# MONTHLY NOTICES

OF THE

# ROYAL ASTRONOMICAL SOCIETY

Vol. III No. 2 1951

## ANNUAL REPORT OF THE COUNCIL

*Published and Sold by the*
ROYAL ASTRONOMICAL SOCIETY
BURLINGTON HOUSE
LONDON, W. 1

*Price Nine Shillings*

## NOTICE TO AUTHORS

1. *Communications.*—Papers must be communicated to the Society by a Fellow. They should be accompanied by a summary at the *beginning* of the paper conveying briefly the content of the paper, and drawing attention to important new information and to the main conclusions. The summary should be intelligible in itself, without reference to the paper, to a reader with some knowledge of the subject; it should not normally exceed 200 words in length. **Authors are requested to submit MSS. in duplicate. These should be typed using double spacing and leaving a margin of not less than one inch on the left-hand side. Corrections to the MSS. should be made in the text and not in the margin.** Unless a paper reaches the Secretaries more than seven days before a Council meeting it will not normally be considered at that meeting. By Council decision, MSS. of accepted papers are retained by the Society for one year after publication; unless their return is then requested by the author, they are destroyed.

2. *Presentation.*—Authors are allowed considerable latitude, but they are requested to follow the general style and arrangement of *Monthly Notices*. References to literature should be given in the standard form, including a date, for printing either as footnotes or in a numbered list at the end of the paper. Each reference should give the **name and initials** of the author cited, irrespectively of the occurrence of the name in the text (some latitude being permissible, however, in the case of an author referring to his own work). The following examples indicate the style of reference appropriate for a paper and a book, respectively :—

A. Corlin, *Zeits. f. Astrophys.*, **15**, 239, 1938.
A. S. Eddington, *Internal Constitution of the Stars*, Cambridge, p. 182, Table 24, 1926.

3. *Notation.*—Authors should conform closely to the recommendations of Commission 3 of the International Astronomical Union (*Trans. I.A.U.*, Vol. VI, p. 345, 1938). Council has decided to adopt the I.A.U. 4-letter abbreviations for constellations where contraction is desirable (Vol. IV, p. 221, 1932).

4. *Diagrams.*—**These should be drawn about twice the size required in print and prepared for direct photographic reproduction except for the lettering, which should be inserted in pencil. Legends should be given in the manuscript indicating where in the text the figure should appear.** Blocks are retained by the Society for 10 years; unless the author requires them before the end of this period they are then destroyed.

5. *Tables.*—**These should be arranged so that they can be printed upright on the page.**

6. *Proofs.*—Costs of alterations exceeding 5 per cent of composition must be borne by the author. Fellows are warned that such costs have risen sharply in recent years, and it is in their own and the Society's interests to seek the maximum conciseness and simplification of symbols and equations consistent with clarity.

7. *Revised Manuscripts.*—When papers are submitted in revised form it is especially requested that they be accompanied by the original MS.

### *Reading of Papers at Meetings*

8. When submitting papers authors are requested to indicate whether they will be willing and able to read the paper at the next or some subsequent meeting, and approximately how long they would like to be allotted for speaking.

9. Postcards giving the programme of each meeting are issued some days before the meeting concerned. Fellows wishing to receive such cards whether for Ordinary Meetings or for the Geophysical Discussions or both should notify the Assistant Secretary.

Professor W. M. Smart, M.A., D.Sc.
*President*, 1949–1951

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ROYAL ASTRONOMICAL SOCIETY

Vol. 111 No. 2

## ANNIVERSARY MEETING OF 1951 FEBRUARY 9

Professor W. M. Smart, President, in the Chair

The election by the Council of the following Fellows was duly confirmed :—

Keith Wesley Abineri, 102 Chalk Hill Road, Wembley Park, Middlesex (proposed by P. A. Moore);

Colin Richards Bassett, 55 Chichester Road, Kilburn Park, London, N.W.6 (proposed by E. M. Burbidge);

Michael Laurence Bateman, F.B.H.I., Merriemede, Old Windsor, Berkshire (proposed by H. Spencer Jones);

Denis Wardlaw Beggs, The Observatories, Madingley Road, Cambridge (proposed by R. O. Redman);

Colin William Binns, B.A., 46 Dillotford Avenue, Styvechale, Coventry (proposed by A. Hunter);

Frank William Cousins, A.M.I.E.E., A.C.I.P.A., 235 Bilton Road, Greenford, Middlesex (proposed by W. H. Steavenson);

Armin J. Deutsch, Ph.D., Mount Wilson and Palomar Observatories, Pasadena, California, U.S.A. (proposed by C. Payne-Gaposchkin);

U Aung Hla, M.A., University of Rangoon, Burma (proposed by W. M. Smart);

Anstruther Pettigrew Macfarlane, M.A., B.Sc., 47 Strathmore Street, Bridgend, Perth (proposed by W. M. Smart);

Joseph Lade Pawsey, M.Sc., Ph.D., Radiophysics Laboratory, University Grounds, City Road, Chippendale, N.S.W., Australia (proposed by (R. v. d. R. Woolley);

Archibald Edmiston Roy, B.Sc., 51 Cresswell Street, Hillhead, Glasgow, W.2 (proposed by W. M. Smart);

Siegfried Singer, Ph.D., American Embassy, 34 Grosvenor Square, London, W.1 (proposed by F. J. M. Stratton);

Stefan Friedrich Smerd, B.Sc., Radiophysics Laboratory, University Grounds, City Road, Chippendale, N.S.W., Australia (proposed by R. v. d. R. Woolley); and

Frank Edwin Wallace, Cris Cras, Wick Lane, Wickford, Essex (proposed by A. Hunter).

The election by the Council of the following Junior Member was duly confirmed :—

Kenneth Ronald Walter Brewer, University of London Observatory, Mill Hill Park, N.W.7 (proposed by E. M. Burbidge).

Eighty-four presents were announced as having been received since the last meeting, including :—

Natalis Durret, *Theoria Planetarum Brevis ex Operibus Kepleri Collecta* (presented by Mr H. G. Wyatt).

The President announced that Professor A. Pannekoek would deliver the George Darwin Lecture at the Ordinary Meeting on 1951 April 13, taking the Origins of Astronomy as his subject.

The President gave an address on the award of the Gold Medal to Professor Antonie Pannekoek. (See p. 245.)

The President then delivered his address on "The First Half of the Twentieth Century—a Partial Review". (See p. 247.)

## ANNUAL GENERAL MEETING 1951 FEBRUARY 9

Professor W. M. Smart, President, in the Chair

The Minutes of the preceding Annual General Meeting were read, confirmed and signed.

The Minutes of the Special General Meeting of 1950 December 8 were read, confirmed and signed.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year.

The Secretary read extracts from the Narrative Report of the Council.

The Report of the Honorary Auditors was read (see p. 138).

The Treasurer gave a brief explanation of the accounts and a survey of the Society's financial position.

A vote of thanks to the Honorary Auditors of the Treasurer's accounts for 1951 was proposed and carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Honorary Auditors and the President's Address.

The Treasurer, on behalf of the Council, moved the adoption of the following additional Section to the Bye-laws, with re-numbering of subsequent Sections and Bye-laws accordingly. The motion was put to the Meeting, and after some discussion, adopted unanimously :—

### Section XVIII.—*Of the Eddington Medal*

79. The services to astronomy and to the Society of Arthur Stanley Eddington (1882–1944) shall be commemorated by the award from time to time of a gold medal to be known as the Eddington Medal.

80. The Medal shall be awarded by the Council at intervals of not less than one year for a specific investigation or a group of related investigations in

astronomy, with a preference for theoretical astronomy, more especially those branches in which Eddington worked, but not excluding celestial mechanics. If the investigation deemed worthy of the award is the joint work of two or more persons, an impression of the Medal shall be given to each of the joint recipients.

81. The Council shall consider each year the propriety of making an award of the Eddington Medal.

The Scrutineers reported to the President the result of the ballot, and the names of the Officers and Council elected for the ensuing year were read to the Meeting. (The list of names is given on p. 265.)

The thanks of the Society were given to the retiring President (Professor W. M. Smart), Vice-President (Dr. R. d'E. Atkinson), and other retiring members of Council.

The thanks of the Meeting were given to the Scrutineers of the ballot.

The Meeting then adjourned.

# REPORT OF THE COUNCIL TO THE HUNDRED AND THIRTY-FIRST ANNUAL GENERAL MEETING OF THE SOCIETY

1. ***The Science Centre.***—Any report on the state of the Society's fortunes at the close of 1950 must give pride of place to the announcement by the Lord President of the Council in the House of Commons on November 21 that " it has been possible to overcome the remaining obstacles for the adoption of the long-term proposals originated by the Royal Society for a British Science Centre in London ". This statement marks a turning-point in the long negotiations on this subject, initiated by the Royal Society in 1943 and steadily pursued by that body ever since. The cooperation of the Royal Astronomical Society, in common with that of other scientific bodies in Burlington House and elsewhere, was sought early in 1944; it was promised with enthusiasm then and has been steadfastly given at each stage thereafter. On many occasions during the last seven years prospects for the success of the scheme have looked bleak, but it is now learned that H.M. Government has offered to provide not only the site—a central and indeed commanding one, of fully adequate size, the location of which should be made public early in 1951—but also the cost of erecting a dignified building worthy of housing the premier scientific academies of the British Commonwealth.

Throughout the later part of this long period of negotiation the Council made known its estimates of the future needs of the Society, and its opinions on the many alternative schemes suggested, through its representative on the Scientific Societies Accommodation Committee, Mr D. H. Sadler. In his long and active service as Secretary during and after the second World War, Mr Sadler acquired an intimate knowledge of the Society's requirements that peculiarly fitted him for this function; and in performing it so efficiently he has placed the Society still further in his debt. It will not come as a surprise to Fellows to learn that when, in 1950 November, the Committee was reconstituted with rather more detailed terms of reference designed to cover the next stage in the evolution of the Science Centre, the Council was unanimous in asking Mr Sadler to serve as the Society's plenipotentiary representative.

In his Anniversary Address for 1950 the President of the Royal Society has already publicly expressed the thanks of the scientific societies to those members of the Government most intimately concerned with the present happier turn of events; it is fitting here to record the appreciation which all Fellows of the Royal Astronomical Society will feel for the effective way in which the Royal Society itself advanced the claims of Science to a worthy home in London and pursued those claims to the present favourable stage. Much of course remains to be done, but we are assured of a start as soon as resources can be found, and the Royal Society hopes to celebrate the tercentenary of its foundation in the new Science Centre in 1960. The Council will continue to cooperate in every effective way it can towards making that hope a reality.

2. *Membership.*—The Council regrets to record the deaths of the following Fellows; these occurred in 1950 except where an earlier year is indicated:

*T. P. Bhaskara Shastri
Austin Alexander Rodney Boyce (1948)
Arthur Burnet
Evan P. Cameron
*Charles John Philip Cave
*Leslie John Comrie
Sir Arthur Mostyn Field
Henry Reginald Fry
*Henry Hermann Gruning
*Rev. Sir John Charles William Herschel
Frank Hope-Jones
Samuel Keir (1949)
*Rev. George Harold Lancaster
George Henry Livens
*Arthur Courtauld Willoughby Lowe
*Rev. Percy Marshall
*Edward Arthur Milne
William Henry Owston
William Morton Page
John Rees (1949)
Dhirendra Nath Saha
Charles Frederick Ortmann Smith (1949)
Roland Dale Thompson
Charles J. Westland

* Life Fellow.

Obituary Notices of some of these Fellows are printed on pp. 154–175. A detailed analysis of the membership of the Society is given in tabular form on p. 139.

3. *Finance.*—The Treasurer presents his annual accounts in the customary form on pp. 140–145.

The Annual General Meeting in 1950 February sanctioned an increase of approximately 50 per cent in the scale of composition fees. The Council does not seek to conceal the fact that in proposing this increase its motive was only partly to supplement the Composition Fund, and thereby the annual revenue of the Society: a more compelling reason was that with the value of money continually falling, the Society found itself at an increasing economic disadvantage *vis-à-vis* its compounders. The increase was therefore designed to discourage compounding except on terms that were much more favourable to the Society.

A number of Fellows who compounded in the past under the more favourable terms then available have made donations to the Society, some under seven-year covenants. Recovery of income tax paid in respect of these covenants has been obtained. The amount received from these special donations has been added to the Composition Fees Reserve Fund.

The Society has received through the Royal Society from the Parliamentary Grant-in-Aid for Scientific Publications a grant of £1,000 towards the cost of printing the publications of the Society, and a grant of £200 towards library expenses. A special grant of £1,500 for dealing with the post-war arrears of publications has also been made. The General Fund Revenue Account consequently shows a surplus for the year of £2,081 17*s.* 11*d.* It must be recalled, however, that in the previous four post-war years 1946–1949, during which the publications have been brought up to current date, the Society has had an accumulated deficit of £2,593 18*s.* 5*d.*

The heavy increases in the cost of printing, amounting since 1939 to about 125 per cent, have been one of the major factors that have complicated the post-war financial position of the Society. The price of the publications of the Society

has not been increased in the same ratio. The Council have decided that the price of all publications shall be increased by approximately 50 per cent, thereby bringing the total increase in price since 1939 into approximate agreement with the increase in printing costs. Commencing with Vol. **112,** the price of the *Monthly Notices* will accordingly be increased to £4 per volume, the price of a single number becoming 13*s.* 6*d.*

During the year the Council has decided to close the Suspense Account. This device for suspending Fellowship was adopted in 1940 largely to mitigate the consequences of the war to Fellows living in countries no longer in postal communication with Great Britain, and was continued after the war ended because monetary exchange difficulties persisted. It is true that such difficulties have even now not been completely removed, but where they still exist there seems no foreseeable likelihood of their early removal. Meanwhile it does not accord with the realities of the situation to permit Fellows on the Suspense Account to go on accumulating arrears indefinitely. The ten Fellows concerned have therefore been informed that though their names must now be removed from the List of Fellows, the Council has powers to allow them to resume their Fellowship at any time without payment of Admission Fee.

The Council has accepted with gratitude from the executors of the late Mrs M. A. Nadarov a bequest of one-half of her residuary estate " for the encouragement and promotion of the study of sunspots". Under the terms of the will the bequest, which amounts to approximately £750, forms the Victor Nadarov Fund, and the executors have agreed that it may be expended as to capital or income at the Council's discretion for the purpose specified.

4. *Seven-year covenants.*—The seven-year covenant scheme, which was explained at length in the Council's report last year (*M.N.*, **110,** 103), met with an unexpected setback when the Inland Revenue authorities disallowed many of the Society's claims for repayment of income tax.

Where Fellows had covenanted to pay their annual contributions for seven years out of taxed income, it had been expected that the Society would be able to recover the tax paid. In disallowing such claims the Inland Revenue Department pointed out that the Society's Bye-laws already imposed on all Fellows a legal obligation to pay their annual contributions. In so far as a covenant relates to no more than this contribution, the Inspector of Taxes (Claims) took the view that the payment is made not by virtue of the deed of convenant, but in satisfaction of the existing legal liability, and accordingly he refused repayment. (Where the covenant is in respect of some voluntary payment unrelated to the annual contribution, no such obstacle arises; and tax has in fact been successfully recovered in such cases.)

In order to meet this situation the Council recommended, and a Special General Meeting in December agreed, that the Bye-laws should be modified so as to relieve Fellows of any legal liability to pay annual contributions. By this means the Society loses the right to sue defaulting Fellows for overdue subscriptions; but this right was never in fact exercised. Where necessary, the Council will continue (it hopes as rarely as at present) merely to operate the present procedure of striking the names of defaulters from the List of Fellows. Meanwhile there is now good ground for believing that by this modification of

the Bye-laws the obstacle to recovering tax in respect of covenanted subscriptions has been removed. It will not be necessary to renew existing covenants: tax will simply be recovered on them for six years instead of seven. Each Fellow who did not respond earlier to the Treasurer's appeal and who is liable to the full rate of United Kingdom income tax is again urged to pay his annual contribution under a seven-year covenant. By this simple act—the paper work involved is quite negligible—and without engaging in any immediate or future financial commitment beyond what is already involved in continued membership for seven years, a participating Fellow can almost double the value of his annual payment to the Society. The total number of covenanters is now 140; if this figure could be raised to 400 out of a membership that is now over 1000, the Society could look forward to a tolerably secure financial future.

5. *Meetings.*—During 1950 the usual eight Ordinary Meetings and six Geophysical Discussions were held in Burlington House. The recent custom of holding annually one additional Ordinary Meeting and one additional Geophysical Discussion in some city remote from London was continued by accepting the kind invitation of the Royal Irish Academy to meet in Dublin during the later part of September. A shadow was cast over this gathering of some 80 Fellows and their guests by the sudden death of Professor E. A. Milne on his way to the first meeting. That the visit (which is reported in *M.N.*, **110**, 263) was otherwise an unqualified success was due largely to the unremitting efforts of Professor H. A. Brück, Director of the Dunsink Observatory; and the Society's particular thanks must be recorded also to the President and Council of the Royal Irish Academy for their hospitality.

Astronomers from overseas addressed the Society on many occasions during the year. Mr Bowe, of the Commonwealth Observatory at Canberra, read a paper by Dr Hogg and himself on the variable star S Antliae at the January meeting; Professor Becker, Director of the Bonn Observatory, described work in progress there at the March meeting; and in April Mr Clemence, Director of the U.S. Nautical Almanac Office, gave an account of recent American work on the motion of the planets. Dr Hubble, of the Mt. Wilson and Palomar Observatories, showed some photographs taken by the 200-in. reflector to the May meeting, which also welcomed Professor Michkovitch, Director of the Institute of Theoretical Astronomy at Belgrade, who described the present state of astronomy in Yugoslavia, and Mr Bolton, of Sydney, who spoke on recent Australian research on galactic radio noise. At the Dublin meeting Professor Menzel, of the Harvard College Observatory, gave an account of his system of prominence classification and illustrated his remarks with a recent motion picture of active prominences; and Professor Zanstra, Director of the Astronomical Institute at Amsterdam, read a paper on polarization in prominences. At the October meeting Professor Yusuke Hagihara, Director of the Tokyo Astronomical Observatory, spoke briefly on progress made in astronomy in Japan since the war, and Dr J. L. Pawsey, of Sydney, spoke on recent developments in radio astronomy in Australia; and in December Professor Aung Hla, of the University of Rangoon, gave an account of the study of astronomy in Burma, and of the difficulties caused by lack of instruments and equipment.

6. *The Gold Medal.*—The Council awarded the Gold Medal of the Society for 1950 to Professor Joel Stebbins for his development of physical methods in astronomical photometry and for the results obtained by the use of those methods. The medal was presented to a proxy at the Anniversary Meeting in February, when the President (Professor W. M. Smart) made the work of Professor Stebbins the basis for his Presidential Address (*M.N.*, **110,** pp. 179–195); but the Society took pleasure in welcoming the Gold Medallist in person in October, when he gave the George Darwin Lecture on " The Electrical Photometry of Stars and Nebulae ". The text of the lecture appears in *M.N.*, **110,** pp. 416–428.

7. *The Eddington Memorial Fund.*—In accordance with the terms of the appeal inaugurated three years ago, it is proposed that the income from this fund, which now stands at just over £500, shall be devoted to commemorating the late Sir Arthur Eddington's services to astronomy and to the Society by the award from time to time of an Eddington Medal for a specific piece of work in astronomy, especially in those branches of theoretical astronomy in which Eddington's chief interests lay. Bye-laws giving effect to these proposals are submitted to the Fellows at this Annual General Meeting, and if they are approved the Council will take into consideration in October 1951 the award of the first Eddington Medal in 1952.

It may not be out of place here to explain the intentions of the Council in more detail than the Bye-laws can appropriately indicate. It is not intended to lay down as a condition of the award either that candidates shall be Fellows or Junior Members of the Society, or that the work deemed worthy of the award shall have been published by the Society. Though no explicit restriction on the age of a candidate is proposed, it was clearly envisaged by the Council when the Bye-laws were drawn up that the Eddington Medallist will normally be younger, often very much younger, than, for example, a Gold Medallist. The Gold Medal is often awarded for the candidate's life work in astronomy : there is no intention of making this the practice with the Eddington Medal, which will be given for a single specific investigation or closely-knit group of related investigations. This work would not be excluded from consideration if an Eddington Medallist were subsequently nominated for the Gold Medal. The Council will endeavour to make and to preserve, not merely in the minds of Fellows in close touch with the Society, but also amongst astronomers throughout the world, a clear distinction between the two awards, the Gold Medal remaining the highest honour the Society can bestow.

8. *Publications.*—During 1950 the Society published and distributed the following :

*Monthly Notices*, Vol. **109,** Nos. 5 and 6; Vol. **110,** Nos. 1, 2 and 3.
*Geophysical Supplement*, Vol. **6,** Nos. 1 and 2.

At the end of the year *M.N.*, Vol. **110,** No. 4 was in page proof and much of No. 5 was in galley. A new List of Fellows of the Society was published in October.

Fellows will have noted one innovation during 1950, namely, the appearance of abstracts of certain Observatory publications at the end of some issues of *Monthly Notices*. This is intended to serve a double purpose. First, Fellows and subscribers at a distance from library facilities will be kept in better touch with current developments without the Society's being put to the expense of publication *in extenso* where other sources of funds for printing are available to the Observatory concerned. Second, since no Observatory will have a circulation list as extensive as that of *Monthly Notices*, the abstract will give wider publicity than would otherwise accrue to the work of the Observatory publishing the paper in full. The scheme is confined to Observatories in the United Kingdom, Eire and the British Commonwealth; and Directors of these who publish bulletins of their own are invited to submit abstracts of papers of general interest for publication in *Monthly Notices*.

Another innovation will have attracted less attention, though it is directed to the same end of improving the usefulness of the Society's publications to Fellows. Those half-tone illustrations in which the reproduction of the finest detail is desired are now being printed through a finer screen and on calendered paper of better quality than heretofore; moreover, the slight further loss of detail inevitable with machine work is avoided by binding into the finished parts plates pulled individually by hand at the blockmakers. This stricter control over the quality of half-tone plates should appreciably improve the faithfulness with which photographic illustrations are reproduced.

The Society's holding of back numbers of *Monthly Notices* has been reduced so that the stock of no part published before 1930 greatly exceeds 50. This measure was necessary in order to release space in the stockroom for storing current issues. The resulting surplus was offered *gratis* to Fellows and Observatories who would undertake to refund the cost of packing and postage. The response to this offer has been so great that the office staff cannot cope with the physical task of dispatching the copies. The Council has therefore decided to accept the offer of Messrs Wm. Dawson & Sons to take over the entire surplus on condition that they distribute, at cost of packing and postage, those copies already ordered. The remaining copies will become the property of the firm, who will pay the Society a 50 per cent commission on future sales.

The Council has given permission to University Microfilms, of Ann Arbor, Michigan, to photograph and distribute *Monthly Notices* and *Memoirs* in microfilm form. The scheme is designed to benefit libraries which, though not primarily astronomical, subscribe to the Society's publications for the occasional use of their readers. These can henceforward obtain, to replace their paper copies at the end of each year, a microfilm edition of the complete volume for about the same sum as would be needed to bind the separate parts. The saving in shelf space is of course considerable. There can be no loss of subscription revenue to the Society, since the microfilm edition will be on sale only to *bona fide* subscribers to the paper edition; and indeed the licensee will pay to the Society a royalty of 10 per cent on the price of each microfilm sold.

9. "*Occasional Notes*."—It is regretted that no number of *Occasional Notes* was issued during the year, in spite of the hope expressed two years ago that at least three would appear annually. The Council regards as a matter of urgency the re-establishment of this link between the Society and its less

academically minded Fellows, and has devoted considerable time during the year to discussing means of effecting this. The Editorial Board has been reconstituted and enlarged, and will meet to plan future numbers at least once a year. It is intended that issues shall revert to the original format, normally comprising short articles of a few pages only. As an experiment, the Editor is preparing a number containing a descriptive account of several astronomical papers on related subjects (some perhaps mainly mathematical) appearing in foreign journals. These developments are welcome, but it is emphasized that no complete solution can be found without the willing cooperation of senior Fellows who are competent to write non-technical reviews of current work in fields of which they have special knowledge. The Council earnestly invites this cooperation.

10. *The Library.*—The average number of visitors to the Society's rooms for the purpose of consulting the Library was 95 a month; 500 books were lent to 134 different borrowers.

On p. 152 appears a list of those institutions and persons who have presented gifts to the Library during 1950 otherwise than by exchange.

In 1950, as in 1949, part of the Parliamentary Grant-in-Aid for Scientific Publications was earmarked for library purposes, and the Council gratefully records the grant by the Royal Society of £200 from this source.

Reports have been received from most of the experts invited to advise on the reorganization of sections of the Library. All the books they have recommended discarding as unsuitable or as duplicating works already on the shelves are being individually examined by the Library Committee, which has met on no fewer than fourteen occasions during the year. Some minor amendments to the Library of Congress system of classification have been adopted to meet the special needs of the Society's Library, and the preparation of the new classified catalogue is proceeding. The Society has been fortunate in retaining the services of Miss E. Wadsworth as part-time Librarian throughout the year.

New shelving for library expansion has been erected in a room on the top floor, now cleared of back publications; and steel cupboards capable of being locked have been bought and are ranged along the north wall of the Council Room ready to receive the Society's more valuable books when the physical reorganization of the Library takes place.

The Council has gratefully accepted the gift by Mr Stephan Kuffner, son of the late owner of the von Kuffner Sternwarte, a private observatory in Vienna, of the library of that institution, stored in 91 packing-cases. The terms of the gift allow the Society to keep such of the books as are required for the Library and to dispose of the remainder. The cases arrived in Great Britain in June and are awaiting examination at the Royal Observatory, Greenwich, where, through the kindness of the Astronomer Royal, they are in temporary store.

11. *The Society's premises.*—The Library and rooms were closed for cleaning from August 21 to September 2 inclusive. During this period the Council Room and the Meeting Room were redecorated, and the carpet in the Upper Library (which was so badly worn as to be dangerous) was taken up and the floor stained.

At the request and at the expense of the London Mathematical Society louvres controllable from the dais have been fitted to the ventilating shafts which pierce the west wall of the Meeting Room.

The portrait of Sir William Herschel which hangs above the President's chair in the Meeting Room has been cleaned and restored, the entire cost being defrayed by Mr W. H. White, who has been warmly thanked for his generosity.

A sub-committee of the House Committee has examined and reported on all the pictures in the possession of the Society. The Council hopes that the rearrangement of the portraits which has resulted from this report will meet with Fellows' approval. The Society's collection of portraits of astronomers will in future be maintained by inviting all newly elected Associates and Medallists of the Society to present their portraits. Mr P. J. Melotte has kindly offered to compile a descriptive card catalogue of all the Society's portraits.

12. *The Isaac Newton Observatory.*—The third Annual Report of the Board of Management appears as Section X of the Astronomer Royal's 1950 Report to the Board of Visitors of the Royal Greenwich Observatory.

The Council has appointed Dr J. A. Carroll to succeed Professor P. M. S. Blackett as the Society's representative on the Board of Management, to serve for the three years beginning on 1951 January 1.

13. *Festival of Britain.*—An Advisory Panel set up with the Society's cooperation two years ago suggested to the organizers a list of topics which should be given some form of visual presentation in the Festival of Britain, and advised on the selection of consultants for each topic. The exhibits designed in accordance with detailed plans drawn up by these consultants are in an advanced stage of construction, and it is believed that when the Festival opens astronomy will be found to be worthily represented, mainly in the Outer Space section of the Dome of Discovery, but also linked with related topics elsewhere. Much of the British contribution to astronomy, however, does not lend itself to visual display, and the Director (Science) of the Festival has undertaken to lay before the B.B.C. certain proposals made by the Council for radio and television programmes on astronomical subjects during 1951.

14. *Radio astronomy.*—The year has been an active one for the Radio Astronomy Committee. The Council has endorsed a proposal put forward by the Physical Laboratories of the University of Manchester for the erection in the United Kingdom of a steerable paraboloid aerial 250 ft. in diameter; has urged the provision of funds for continuing research and routine observational work in radio astronomy at the Cavendish Laboratory at Cambridge; and has supported a proposal by the Army Operational Research Group to make radio observations at the total solar eclipse of 1952 February 25.

It is as a result of a recommendation by the Radio Astronomy Committee that this Annual Report contains for the first time (pp. 176–218), in the section on Proceedings of Observatories, summaries of the year's work at various establishments working in this field.

15. *Astronomical photographs.*—By an agreement with the California Institute of Technology, the Society will act as European distribution centre for prints of objects photographed with the 200-inch telescope and the 48-inch Schmidt camera on Mount Palomar. A preliminary consignment of copy negatives now being assembled should enable the Society's collection of photographs to be valuably extended.

16. *Guest Societies.*—The British Astronomical Association and the London Mathematical Society held meetings during the year in the Society's rooms. On July 25 members of the London Conference on Optical Instruments were entertained at an informal gathering which included a lecture entitled "New Tools for Solar Physics" by Dr M. A. Ellison. Facilities for meetings were afforded to certain Committees of the British Association and of the Board of Management of the Isaac Newton Observatory.

17. *Representation of the Society.*—The Council has made the customary provision for the representation of the Society on such outside bodies as require it.

At the Centenary Meeting of the Royal Meteorological Society in March the Foreign Secretary represented the Society, and conveyed an address containing the warmest congratulations of British astronomers on the occasion.

The Society was represented at the memorial service for the late Professor E. A. Milne and at the funeral of Dr L. J. Comrie by Dr A. Hunter (Secretary).

## REPORT OF THE AUDITORS FOR THE YEAR 1950

We have examined the accounts of the Society and approve the various items of expenditure. Again there is a substantial adverse balance of expenditure over revenue, apart from the substantial grants made by and through the Royal Society, which are very welcome; however, it is to be noted that some arrears in printing have been made up, while no income tax has yet been recovered on covenanted subscriptions, so that the position is very similar to last year.

We have checked the official list of Fellows against subscriptions received. The increase in membership continues, though rather less rapidly.

We have examined the premises of the Society. Since last year a certain amount of interior decoration has been carried out, but more is still needed. A new thermostatically controlled water heater should be fitted over the gentlemen's wash-basin for safety reasons.

Finally, we gratefully acknowledge the help and the cooperation given us by the Assistant Secretary in providing the information that we required.

J. C. P. MILLER.
K. C. BLACKWELL.

## PROGRESS AND PRESENT STATE OF THE SOCIETY

| | Patron | Institutional Members | Fellows | | | Junior Members | Associates | Total |
|---|---|---|---|---|---|---|---|---|
| | | | Compounders | Annual Contributors | Non-active Fellows | | | |
| 1950 January 1 ... ... ... | 1 | 6 | 214 | 719 | 10 | 30 | 51 | 1031 |
| Adjustment ... ... ... | ... | ... | 213 | 720 | ... | ... | ... | ... |
| Since elected ... ... ... | ... | ... | + 3 | +62 | ... | +11 | ... | ... |
| Junior Member elected to Fellowship ... ... ... ... | ... | ... | ... | + 1 | ... | − 1 | ... | ... |
| Deceased 1950 ... ... ... | ... | ... | − 9 | − 9 | ... | ... | ... | ... |
| Deceased prior to 1950, death not notified ... ... ... ... | ... | ... | ... | − 4 | ... | ... | ... | ... |
| Since compounded ... ... | ... | ... | + 8 | − 8 | ... | ... | ... | ... |
| Resigned 1950 ... ... ... | ... | ... | ... | −16 | ... | − 2 | ... | ... |
| Names removed ... ... ... | ... | ... | ... | −14 | − 8 | ... | ... | ... |
| Transferred 1950 from "War Conditions" to Active ... ... | ... | ... | ... | + 2 | − 2 | ... | ... | ... |
| 1951 January 1 ... ... ... | 1 | 6 | 215 | 734 | ... | 38 | 51 | 1045 |

(N.B.—Nine Associates are also Fellows, and are therefore counted twice in the above table.)

*Cash*

| RECEIVED | £ s. d. | £ s. d. | £ s. d. |
|---|---|---|---|
| **Balances, 1950 January 1 :—** | | | |
| In hand of Assistant Secretary, on Petty Cash Account ... ... ... | | 14 13 0 | |
| At Westminster Bank, on Current Account as per Pass Book ... ... | 2,051 16 7 | | |
| *Less* Cheques not presented ... ... ... ... ... ... | 97 5 11 | | |
| | 1,954 10 8 | | |
| *Add* Foreign drafts not credited till 1950 ... ... ... ... | 8 1 11 | | |
| | | 1,962 12 7 | |
| At Westminster Bank, on "B" Account :— | | | |
| A. S. Williams Bequest ... ... ... ... ... ... | | 52 10 0 | |
| At Westminster Bank, on "C" Account :— | | | |
| Trust Funds, as per Pass Book (including Sale of Duplicate Books Fund, £34 11s. 2d.) ... ... ... ... | 348 19 11 | | |
| *Add* due from General Account ... ... ... ... ... ... | 41 12 0 | | |
| | | 390 11 11 | |
| At Post Office Savings Bank :— | | | |
| General Fund ... ... ... ... ... ... ... ... | 2,835 9 8 | | |
| "C" Account ... ... ... ... ... ... ... ... | 741 0 10 | | |
| Staff Pension Fund ... ... ... ... ... ... ... | 500 6 1 | | |
| | | 4,076 16 7 | |
| At London Savings Bank :— | | | |
| Ordinary Department (including £250 A. S. Williams Bequest) ... | 1,746 18 8 | | |
| Special Investment Department ... ... ... ... ... ... | 629 11 3 | | |
| | | 2,376 9 11 | |
| | | | 8,873 14 0 |
| **Parliamentary Grant-in-Aid for Scientific Publications, received through the Royal Society for 1950** ... ... ... ... ... ... | | | 1,000 0 0 |
| **Eddington Memorial Fund : Subscriptions received** ... ... ... ... | | | 7 7 0 |
| **Special Donations** ... ... ... ... ... ... ... | | 137 1 3 | |
| *Add* Tax recovered on those under covenant ... ... ... ... ... | | 46 1 4 | |
| | | | 183 2 7 |
| **Dividends on Investments** ... ... ... ... ... .. ... ... | | 698 4 0 | |
| **Interest on Savings Banks Deposits** ... ... ... ... ... | | 142 15 6 | |
| **Income Tax refunded : 1949 April to December** ... ... ... ... | 135 14 7 | | |
| **1950 January to April** ... ... ... ... | 69 6 10 | | |
| | | 205 1 5 | |
| **Sales of Publications :—** | | | |
| ***Monthly Notices*, 1948 and earlier** ... ... ... ... ... ... | 309 10 1 | | |
| " " **1949** ... ... ... ... ... ... ... ... | 39 12 2 | | |
| " " **1950** ... ... ... ... ... ... ... ... | 551 11 5 | | |
| " " **1951 in advance** ... ... ... ... ... ... | 41 8 0 | | |
| ***Geophysical Supplement*** ... ... ... ... ... ... ... | 211 17 2 | | |
| **Memoirs, Occasional Notes and miscellaneous** ... ... ... ... | 72 4 7 | | |
| | | 1,226 3 5 | |
| **Sale of Reprints** ... ... ... ... ... ... ... ... | | 225 11 8 | |
| **Sale of Photographs and Hire of Slides** ... ... ... ... ... ... | | 73 17 9 | |
| **Hire of Films** ... ... ... ... ... ... ... ... ... | | 35 0 0 | |
| **Miscellaneous Receipts :—** | | | |
| **London Mathematical Society** ... ... ... ... ... ... ... | 30 0 0 | | |
| **Assistant Secretary and Librarian, Contributions to Pension Scheme** ... | 66 8 0 | | |
| **Postages repaid : 1949** ... ... ... ... ... ... £9 19 5 | | | |
| **1950** ... ... ... ... ... ... 45 14 4 | | | |
| **1951 in advance** ... ... ... ... 2 19 6 | | | |
| | 58 13 3 | | |
| **British Astronomical Association, 1949 October to 1950 October** ... | 120 0 0 | | |
| **Contribution paid before election** ... ... ... ... ... ... | 5 5 0 | | |
| **Contributions overpaid, and repayable** ... ... ... ... ... | 2 12 6 | | |
| **Donation under covenant to Benevolent Fund and tax recovered thereon** | 1 18 2 | | |
| **Science Library. Photo-copying Service** ... ... ... ... ... | 1 0 9 | | |
| **Royalties on published book** ... ... ... ... ... ... ... | 2 2 0 | | |
| **Sundry Sales** ... ... ... ... ... ... ... ... | 1 7 6 | | |
| | | 289 7 2 | |
| | | | 2,896 0 11 |
| **Received on Account of Contributions :—** | | | |
| **570 Annual Contributions, 1950** ... ... ... ... £1,795 10 0 | | | |
| **7 Partial Contributions, 1950, partly paid in 1949** ... 9 9 0 | | | |
| **3 Partial Contributions, 1950** ... ... ... ... 6 6 0 | | | |
| | 1,811 5 0 | | |
| **6 Institutional Membership Fees** ... ... ... ... ... ... | 18 18 0 | | |
| **31 Junior Members' Annual Contributions** ... ... ... ... ... | 32 11 0 | | |
| **49 Admission Fees, 1950** ... ... ... ... ... £102 18 0 | | | |
| **32 First Contributions at £3 3s.** ... ... ... ... 100 16 0 | | | |
| **16 First Contributions at £1 1s.** ... ... ... ... 16 16 0 | | | |
| **1 Partial First Contribution** ... ... ... ... 5 0 | | | |
| | 220 15 0 | | |
| **Arrears paid off :—** | | 2,083 9 0 | |
| **1 Fellow's Annual Contribution, 1947** ... ... ... £2 2 0 | | | |
| **6 Fellows' Annual Contributions, 1948** ... ... ... 18 18 0 | | | |
| **24 Fellows' Annual Contributions, 1949** ... ... ... 75 12 0 | | | |
| **17 Partial Contributions, 1949** ... ... ... ... 26 16 0 | | | |
| **2 Partial Contributions, 1948** ... ... ... ... 2 12 3 | | | |
| **9 Admission Fees, 1949** ... ... ... ... ... 18 18 0 | | | |
| **8 First Contributions, 1949** ... ... ... ... ... 8 8 0 | | | |
| **2 Institutional Membership Fees, 1949** ... ... ... 6 6 0 | | | |
| | 159 12 3 | | |
| **Contributions in Advance, received 1950 :—** | | | |
| **28 Annual Contributions for 1951** ... ... ... ... £88 4 0 | | | |
| **6 Partial Annual Contributions for 1951** ... ... ... 8 13 0 | | | |
| **1 Annual Contribution for 1952** ... ... ... ... 3 3 0 | | | |
| **3 Partial Annual Contributions for 1952** ... ... ... 4 11 0 | | | |
| **1 Junior Member's Annual Contribution for 1951** ... ... 1 1 0 | | | |
| | 105 12 0 | | |
| **Composition Fees :—** | | | |
| **1 Initial** ... ... ... ... ... ... ... ... £47 5 0 | | | |
| **3 Initial (reduced)** ... ... ... ... ... ... ... 155 18 6 | | | |
| **7 Reduced** ... ... ... ... ... ... ... ... 182 3 6 | | | |
| | 385 7 0 | | |
| | | 650 11 3 | |
| | | | 2,734 0 3 |
| **"C" Account :—** | | | |
| **Victor Nadarov Bequest. Accrued Income to 1950 July (and Capital £11 8s. 0d.)** ... ... ... ... ... ... ... ... | 91 2 11 | | |
| *Add* **Tax recovered thereon** ... ... ... ... ... ... ... ... | 28 13 0 | | |
| | | 119 15 11 | |
| **Dividends on Investments** ... ... ... ... ... ... ... ... | | 228 12 2 | |
| **Income Tax refunded** ... ... ... ... ... ... ... ... | | 19 10 8 | |
| **Interest on Post Office Savings Bank Account** ... ... .. ... | | 18 10 0 | |
| | | | 386 8 9 |
| | | | £16,080 13 6 |

## *Account*

| PAID | £ s. d. | £ s. d. | £ s. d. |
|---|---|---|---|
| **Office Staff**, including Librarian :— | | | |
| Salaries ... ... ... ... ... ... ... ... ... | 915 5 3 | | |
| Income Tax on Salaries... ... ... ... ... ... ... ... | 106 4 0 | | |
| National Insurance ... ... ... ... ... ... ... ... | 25 7 0 | | |
| **Assistant Secretary and Librarian** : Pension Premiums (Society's Contributions £74 5s. 0d.; Staff Contributions £72 15s. 0d.) ... ... ... ... | 147 0 0 | | |
| | | 1,193 16 3 | |
| Porter and Wife : Wages and Cleaning ... ... ... ... ... ... | 277 16 0 | | |
| National Insurance ... ... ... ... ... ... | 19 5 8 | | |
| | | 297 1 8 | |
| Charwoman : Wages... ... ... ... ... ... ... ... ... | | 32 17 6 | |
| | | | 1,523 15 5 |
| Insurance ... ... ... ... ... ... ... ... ... ... | | 15 14 2 | |
| Telephone ... ... ... ... ... ... ... ... ... ... | | 30 1 5 | |
| | | | 45 15 7 |
| Printing, etc. :— | | | |
| *Monthly Notices* (Vol. **108**, Nos. 1, 2, 3, 4, 5 and 6 balance) ... ... | | 744 7 0 | |
| *Monthly Notices* (Vol. **109**, Nos. 1, 2, 3 and 4) ... ... ... ... | | 1,473 1 2 | |
| *Geophysical Supplement* (Vol. **5**, Nos. 7, 8, and 9) ... ... ... ... | | 574 17 7 | |
| Occasional Notes (Nos. 12 and 13) ... ... ... ... ... ... | | 115 9 4 | |
| Miscellaneous and meeting cards ... ... ... ... ... ... | | 216 12 2 | |
| Photo-engraving ... ... ... ... ... ... ... ... ... | | 159 8 6 | |
| Paper Supplies ... ... ... ... ... ... ... ... ... | | 272 19 10 | |
| | | | 3,556 15 7 |
| Postages and Packing :— | | | |
| *Monthly Notices*, etc. ... ... ... ... ... ... ... ... | | 272 11 3 | |
| Office postages ... ... ... ... ... ... ... ... ... | | 101 0 4 | |
| | | | 373 11 7 |
| Stationery and Office Expenses ... ... ... ... ... ... | | 83 6 8 | |
| Heating and Lighting ... ... ... ... ... ... ... | | 183 12 0 | |
| Accountants' Fees ... ... ... ... ... ... ... ... | | 63 0 0 | |
| Subscription to National Central Library ... ... ... ... | | 1 1 0 | |
| Subscription and Conference fee to A.S.L.I.B. ... ... ... | | 8 8 0 | |
| I.A.U. Telegrams ... ... ... ... ... ... ... ... | | 6 16 7 | |
| Authorized Travelling Expenses ... ... ... ... ... ... | | 17 5 4 | |
| Repairs, Fittings and Fixtures (less Contribution from London Mathematical Society £10) ... ... ... ... ... ... ... | | 224 15 1 | |
| House Expenses and Laundry ... ... ... ... ... ... | | 42 2 10 | |
| Expenses of R.A.S. Meetings and Committees ... ... ... ... | | 76 11 10 | |
| Bank Charges and Cheque Books ... ... ... ... ... ... | | 2 17 7 | |
| Library Expenses (including Cabinets, £110 12 6) ... ... ... | | 131 1 6 | |
| Gold Medal ... ... ... ... ... ... ... ... ... | | 14 5 0 | |
| Cost of Covenant Stamps ... ... ... ... ... ... ... | | 10 9 10 | |
| Miscellaneous Expenditure ... ... ... ... ... ... ... | | 17 12 8 | |
| Net deficit on Contributions ... ... ... ... ... ... ... | | 6 9 | |
| Benevolent Fund Grant ... ... ... ... ... ... ... | | 2 2 0 | |
| | | | 885 14 8 |
| Repairs Charged to Reserve Account ... ... ... ... ... | | 14 10 4 | |
| Purchase of Books from Potter Fund ... ... ... ... ... | | 10 10 0 | |
| | | | 25 0 4 |
| Binding Periodicals ... ... ... ... ... ... ... | | | 43 4 8 |
| Reproduction of Slides and Prints ... ... ... ... ... ... | | | 107 4 9 |
| Block Subscription to *The Observatory* ... ... ... ... | | | 160 0 0 |
| Dublin Meeting Expenses ... ... ... ... ... ... ... | | | 36 17 3 |
| Expenditure on Trust Accounts :— | | | |
| Turnor and Horrocks Fund (Library)... ... ... ... ... ... | | 21 3 6 | |
| Harry Watson Fund (Library)... ... ... ... ... ... ... | | 103 8 7 | |
| George Darwin Lectureship Fund ... ... ... ... ... ... | | 50 0 0 | |
| Lee and Jansen Fund ... ... ... ... ... ... ... | | 10 10 0 | |
| | | | 185 8 1 |
| **Balances, 1950 December 31** :— | | | |
| In hand of Assistant Secretary, on Petty Cash Account ... ... ... | | 12 6 8 | |
| At Westminster Bank on Current Account, as per Pass Book ... ... | 2,099 1 3 | | |
| *Less* Cheques not presented ... ... ... ... ... ... | 83 18 4 | | |
| | 2,015 2 11 | | |
| *Less* due to "C" Account... ... ... ... ... ... ... | 132 8 7 | | |
| | | 1,882 14 4 | |
| At Westminster Bank, on "B" Account (A. S. Williams Bequest) ... | | 52 10 0 | |
| At Westminster Bank, on "C" Account :— | | | |
| Trust Funds, as per Pass Book (including Sale of Duplicate Books Fund £34 11s. 2d.) ... ... ... ... ... ... ... | 441 0 0 | | |
| *Add* Due from General Account ... ... ... ... ... | 132 8 7 | | |
| | | 573 8 7 | |
| At Post Office Savings Bank :— | | | |
| General Fund ... ... ... ... ... ... ... ... | 2,906 7 8 | | |
| "C" Account ... ... ... ... ... ... ... | 759 10 10 | | |
| Staff Pension Fund at 1949 December 31 ... ... £500 6 1 | | | |
| *Add* Interest, 1950 ... ... ... ... ... 12 10 0 | | | |
| | 512 16 1 | | |
| | | 4,178 14 7 | |
| At London Savings Bank :— | | | |
| Ordinary Department (including £250 A. S. Williams Bequest) ... | 1,790 11 8 | | |
| Special Investment Department... ... ... ... ... ... | 645 5 9 | | |
| | | 2,435 17 5 | |
| | | | 9,135 11 7 |
| | | | £16,080 13 6 |

*Dr.* **General Fund Revenue Account**

| | £ s. d. | £ s. d. |
|---|---|---|
| To Salaries and Wages, including Pension Premiums and National Insurance | | 1,453 16 1 |
| „ Insurance and Telephone (after adjusting Reserves) | | 45 15 7 |
| „ Printing, etc. (after adjusting Reserves) | 3,060 8 0 | |
| *Less* Amount received from the Parliamentary Grant-in-Aid for Scientific Publications through the Royal Society for 1950 | 1,000 0 0 | |
| | | 2,060 8 0 |
| „ Posting and Packing (after adjusting Reserves) | | 402 12 4 |
| *General Expenses (after adjusting Reserves)* :— | | |
| Stationery and Office Expenses | 96 17 0 | |
| Lighting and Heating | 198 6 3 | |
| Travelling Expenses | 17 5 4 | |
| Subscriptions to National Central Library and A.S.L.I.B. | 9 9 0 | |
| Accountants' Fees | 63 0 0 | |
| Gold Medal | 14 5 0 | |
| Office Furniture and Fittings, including repairs | 116 9 7 | |
| I.A.U. Telegram Service | 6 16 7 | |
| House Expenses | 43 12 10 | |
| Meeting Expenses | 78 13 10 | |
| Sundries | 33 16 10 | |
| | | 678 12 3 |
| „ Block Subscription to *The Observatory* | | 160 0 0 |
| „ Purchase of Books from Potter Fund | | 10 10 0 |
| Reserve for Repairs | | 200 0 0 |
| „ Staff Pension Fund | | 100 0 0 |
| „ Binding of Periodicals, etc. (after adjusting Reserves) | | 29 4 0 |
| „ Reproduction of Photographic Slides and Prints | | 106 18 6 |
| „ Films, Hire and Expenses | | 13 9 |
| „ Dublin Meeting Expenses | | 36 17 3 |
| | | 5,285 7 9 |
| „ Surplus, one year to date | | 2,081 17 11 |
| | | £7,367 5 8 |

*Note.*—The excess of expenditure over income for the four previous years is shown below:

| | |
|---|---|
| 1946 | £540 18 11 |
| 1947 | 971 6 1 |
| 1948 | 968 6 4 |
| 1949 | 113 7 1 |
| | £2,593 18 5 |

*One Year to* 1950 *December* 31 *Cr.*

| | £ s. d. | £ s. d. | £ s. d. |
|---|---|---|---|
| By *Amounts received from Fellows*:— | | | |
| 1 Annual Contribution for 1947 ... ... | 2 2 0 | | |
| 6 Annual Contributions for 1948 ... ... | 18 18 0 | | |
| 2 Partial Annual Contributions for 1948 ... | 2 12 3 | | |
| 24 Annual Contributions for 1949 ... ... | 75 12 0 | | |
| 17 Partial Annual Contributions for 1949 ... | 26 16 0 | | |
| 9 Admission Fees, 1949 ... ... ... | 18 18 0 | | |
| 8 First Contributions, 1949 ... ... ... | 8 8 0 | | |
| 2 Institutional Membership Fees, 1949 ... | 6 6 0 | | |
| 608 Annual Contributions, 1950 ... ... | 1,915 4 0 | | |
| 14 Partial Payments, 1950 ... ... ... | 34 8 0 | | |
| 6 Institutional Membership Fees, 1950 ... | 18 18 0 | | |
| 35 Junior Members' Annual Contributions ... | 36 15 0 | | |
| 51 Admission Fees ... ... ... ... | 107 2 0 | | |
| 49 First Contributions ... ... ... ... | 120 15 0 | | |
| | | 2,392 14 3 | |
| *Composition Fees*:— | | | |
| Initial Fee ... ... ... ... ... | 47 5 0 | | |
| Initial (Reduced) Fees ... ... ... | 159 1 6 | | |
| Reduced Fees ... ... ... ... | 182 3 6 | | |
| | 388 10 0 | | |
| *Add* Special donations from Compounders (including £46 1*s.* 4*d.* tax recovered on covenants) ... ... ... ... | 183 2 7 | | |
| | 571 12 7 | | |
| *Less* Transferred to Reserve Account ... | 571 12 7 | | |
| | – – – | | |
| *Add* Amount brought to Credit for the year | 157 17 0 | | |
| | | 157 17 0 | |
| | | | 2,550 11 3 |
| „ Interest and Dividends received (gross) ... ... ... ... | | 908 0 6 | |
| „ Interest on Bank Deposit Accounts received ... ... ... | | 130 5 6 | |
| | | | 1,038 6 0 |
| „ Income Tax recovered in respect of receipts under covenant ... ... ... ... ... ... ... ... | | 46 18 6 | |
| *Less* Applied to Special Donations from Compounders ... ... ... ... ... | 46 1 4 | | |
| *Less* Applied to Benevolent Fund Donation ... | 17 2 | | |
| | | 46 18 6 | |
| | | – – – | |
| „ Sales of Publications, Photographs and Miscellaneous Receipts for the year ... ... ... ... ... ... ... ... | | | 2,078 8 5 |
| „ Royal Society, Special Grant ... ... ... ... ... ... | | | 1,500 0 0 |
| „ Royal Society Grant towards Expenses of Library ... ... | | | 200 0 0 |
| | | | £7,367 5 8 |

## *Balance Sheet*

| | £ s. d. | £ s. d. |
|---|---|---|
| ***General Fund*:—** | | |
| As at 1949 December 31 ... ... ... ... ... ... | 24,175 8 0 | |
| *Add* Excess of Income over Expenditure, 1950 (including Special Grant of £1,500 from the Royal Society) ... ... ... | 2,081 17 11 | |
| | | 26,257 5 11 |
| ***Trust Funds*:—** | | |
| Capital as at 1949 December 31 ... ... ...£6,707 0 3 | | |
| Victor Nadarov Bequest ... ... ... ... 752 9 11 | | |
| | 7,459 10 2 | |
| Income Balances at 1950 December 31 ... ... ... ... | 1,286 9 10 | |
| Income Tax on Trust Funds, 1950 April–December, not yet refunded ... ... ... ... ... ... ... ... | 22 1 3 | |
| | | 8,768 1 3 |
| ***Arthur Stanley Eddington Commemoration Fund*:—** | | |
| As at 1949 December 31 ... ... ... ... ... ... | 522 5 0 | |
| *Add* amount received 1 year to date... ... ... ... ... | 9 5 0 | |
| | | 531 10 0 |
| ***Reserves*:—** | | |
| Repairs and Maintenance: | | |
| As at 1949 December 31 ... ... ... £195 6 11 | | |
| *Less* Expenditure, 1950 ... ... £214 10 4 | | |
| *Less* Set aside 1950 ... ... 200 0 0 | | |
| 14 10 4 | | |
| | 180 16 7 | |
| Sale of Duplicate Books Fund: | | |
| As at 1949 December 31 ... ... ... | 35 1 7 | |
| | | 215 18 2 |
| ***Composition Fees Reserve Fund*:—** | | |
| As at 1949 December 31 ... ... ... ... ... ... | 2,059 4 11 | |
| Received in 1950 ... ... ... ... ... ... ... | 388 10 0 | |
| Special Donations ... ... ... ... ... ... ... | 183 2 7 | |
| | 2,630 17 6 | |
| *Less* 6 per cent transferred to Revenue Account ... ... ... | 157 17 0 | |
| | | 2,473 0 6 |
| ***Staff Pension Fund*:—** | | |
| As at 1949 December 31 ... ... ... ... ... ... | 500 6 1 | |
| *Add* Interest for 1950 ... ... ... ... ... ... | 12 10 0 | |
| *Add* Amount set aside 1950 ... ... ... ... ... ... | 100 0 0 | |
| | | 612 16 1 |
| ***Benevolent Fund*:—** | | |
| Donations received 1950 (including 17*s.* 2*d.* tax recovery) ... | 4 0 2 | |
| *Less* Grant made... ... ... ... ... ... ... ... | 2 2 0 | |
| | | 1 18 2 |
| ***Amounts received in advance*:—** | | |
| Contributions: | | |
| 1951 paid in 1948 ... ... ... ... 3 3 0 | | |
| 1951 paid in 1949 ... ... ... ... 1 17 0 | | |
| 1951 paid in 1950 ... ... ... ... 97 18 0 | | |
| 1952 paid in 1950 ... ... ... ... 7 14 0 | | |
| | 110 12 0 | |
| Publications, 1951 ... ... ... ... ... 41 8 0 | | |
| Postages, 1951 ... ... ... ... ... ... 2 19 6 | | |
| | 44 7 6 | |
| | | 154 19 6 |
| Sundry Creditors for Accounts due but not presented (including provision for printing publications for 1950 and binding periodicals, not yet completed) ... | | 4,077 7 5 |
| | | £43,092 17 0 |

*To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY.*

We have examined the above Balance Sheet with the Books and Vouchers relating thereto explanations given to us.

We have verified the Securities representing the Investments and have found them to be

SUFFOLK HOUSE,
5 LAURENCE POUNTNEY HILL, LONDON, E.C. 4,
1951 February.

1950 *December* 31

| | £ s. d. | £ s. d. |
|---|---|---|
| ***Investments*** :— | | |
| General Fund, valued as at 1922 December 29 or subsequent cost... | 24,074 11 1 | |
| Trust Funds, valued at cost ... ... ... ... ... ... | 7,448 2 2 | |
| (Market Value 1950 December 31, £34,061) | | 31,522 13 3 |
| ***Debtors*** :— | | |
| General ... ... ... ... ... ... ... ... | 572 1 3 | |
| Royal Society Grants... ... ... ... ... ... | 1,700 0 0 | |
| Income Tax Recoverable : | | |
| General Fund ... ... ... ... ... ... ... | 140 9 8 | |
| Trust Funds ... ... ... ... ... ... ... | 22 1 3 | |
| | | 2,434 12 2 |
| **Deposits at Savings Banks** :— | | |
| General Fund ... ... ... ... ... ... | £5,855 1 2 | |
| Trust Funds ... ... ... ... ... ... | 759 10 10 | |
| | 6,614 12 0 | |
| **Balance on Current Account at Bank and Cash in Hand** :— | | |
| General Fund ... ... ... ... ... ... | 1,947 11 0 | |
| Trust Funds (including sales of Duplicate Books Fund £34 11*s.* 2*d.*) ... ... ... ... | 573 8 7 | |
| | 2,520 19 7 | |
| As per Cash Account ... ... ... ... ... ... | | 9,135 11 7 |
| | | £43,092 17 0 |

*Note.—Contributions unpaid as at 1950 December 31, and amounting to £302 13s., have not been included in this Balance Sheet.*

and certify it to be correctly drawn up therefrom and in accordance with the information and in order.

SHARP, PARSONS & CO.,
*Chartered Accountants.*

## INVESTMENTS

As at 1950 December 31

### *General Fund*

£2000 Swansea Corporation 3½ per cent Stock.
£6723 10*s.* 3*d.* British Transport 3 per cent Guaranteed Stock, 1978/88.*
£496 Consolidated 4 per cent Stock, 1957.
£1035 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent Redeemable Stock, 1952–72.
£700 Birmingham Corporation 3 per cent Inscribed Stock, 1947.
£2280 5*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£1156 1*s.* 5*d.* Metropolitan Water Board 3 per cent "B" Stock.
£500 National Defence Loan, 1954–58, 3 per cent Registered Stock.
£500 Savings Bonds 2½ per cent, 1964/67.
£2118 3*s.* 5*d.* Savings Bonds 3 per cent, 1960/1970. (Holding "A")
£695 16*s.* 0*d.* Conversion Loan 3½ per cent, 1961.
£2239 13*s.* 8*d.* Treasury 2½ per cent Stock, 1975.
£3050 13*s.* 0*d.* British Electricity 3 per cent Guaranteed Stock, 1968–73.*
£3718 British Gas 3 per cent Guaranteed Stock, 1990–95.*
£500 Commonwealth of Australia 3 per cent Loan, 1972–74.*

### *Trust Funds*

£1004 Consolidated 4 per cent Stock, 1957.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent Debenture Stock, 1961–91.*
£491 10*s.* 0*d.* War Loan 3½ per cent Inscribed Stock.
£1160 16*s.* 3*d.* War Loan 3½ per cent Inscribed Stock.
£542 18*s.* 2*d.* Savings Bonds 3 per cent, 1960/1970. (Holding "B")
£1122 19*s.* 6*d.* Savings Bonds 3 per cent, 1960/1970. (Holding "C")
£1471 4*s.* 0*d.* Savings Bonds 3 per cent, 1955/1965.
£375 Savings Bonds 3 per cent 1955/1965.*
£100 Savings Bonds 3 per cent 1960/1970. (Holding "D")
£250 War Loan 3½ per cent Stock.

* *Taxed at source.*

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

*The John Lee Gift* (1836 and 1844): In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were purchased by his heir, Edward Lee, Esq., for £700.

*The Lawson Bequest* (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

*The Carrington Bequest* (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

*The Lambert Bequest* (1877): C. J. Lambert, Esq., presented to the Society the sum of £500 free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

*The McClean Bequest* (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

*The Farrar Bequest* (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

*The Parsons Gift* (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1876 October 31.

*The Grove-Hills Bequest* (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

*The Grove-Hills Fund* (1922): In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913 1*s.* 11*d.*, of which £1480 2*s.* 10*d.* has been invested and is now represented by £355 Agricultural Mortgage 4½ per cent, £423 15*s.* 11*d.* War Stock 3½ per cent, and £695 16*s.* Conversion Loan 3½ per cent 1961.

*The Lindemann Bequest* (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

*The Archdeacon Potter Bequest* (1933) (*see below*).

*The Goodridge Bequest* (1936): Captain J. J. L. Goodridge, who died 1936 March 13, bequeathed to the Society the sum of £50, free of legacy duty. In 1937 the bequest was invested in £49 0*s.* 4*d.* War Stock 3½ per cent.

*The Herbert Spencer Bequest* (1936): Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The bequest was finally expended during 1941.

*The Lindley Bequest* (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which was received from the Public Trustee in the form of £1156 1*s.* 5*d.* Metropolitan Water Board 3 per cent "B" Stock.

*The Stanley Williams Bequest* (1939): A. Stanley Williams, Esq., who died 1938 November 21, bequeathed to the Society all his astronomical instruments, books, maps, photographs, manuscripts, etc., together with the sum of £200, free of legacy duty, for the reduction or publication of his observations of variable stars; and also a further sum of £100, free of legacy duty, for the furtherance of astronomy in general or of the Society in particular, in such manner as the Council of the Society may think fit.

*The E. W. Brown Trust* (1939) (*see below*).

*The Plummer Bequest* (1946) (*see below*).

*The Carder-Davies Bequest* (1948): D. Carder-Davies, Esq., bequeathed to the Society the sum of £3000, free of duty and without any condition, other than the expression of a wish that no part be spent on any purpose controlled or suggested by Government. The legacy has been invested in the following way: £1229 11*s.* in British Electricity 3 per cent Guaranteed Stock; £1770 9*s.* in Treasury 2½ per cent Stock, which have been added to the General Funds of the Society.

*The M. A. Nadarov Bequest* (1950) (*see below*).

### SPECIAL FUNDS

*The Archdeacon Potter Fund* (1933): Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent War Stock, the cash balance of £17 15*s.* 2*d.* having been expended on the library in 1934. The Council resolved to allocate the dividends from this fund for the purposes of the library.

| | £ | s. | d. | | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 14 | 19 | 6 | 1950. Purchase of Books ... | 10 | 10 | 0 |
| 1950. Dividends, War Stock 3½ per cent ... ... ... | 10 | 10 | 0 | 1950 Dec. 31. Balance of Fund... | 14 | 19 | 6 |
| | £25 | 9 | 6 | | £25 | 9 | 6 |

*The Victor Nadarov Fund* (1950): Mrs M. A. Nadarov bequeathed to the Society one-half of her residuary estate. The estate was wound up in 1950, and the Society's share amounted to £725 invested in Savings Bonds and War Stock. Under the terms of the legacy the Fund is to be devoted to the encouragement and promotion of the study of sunspots and is to be known as the Victor Nadarov Fund: subject to this condition, the Fund can be used, both as to principal and accumulated interest, in whatever way the Council considers most suitable. The money is invested in the following securities, which were transferred to the Society: £375 3 per cent Savings Bonds, 1955/1965; £100 3 per cent Savings Bonds 1960/1970; £250 3½ per cent War Stock.

| | £ | s. | d. |
|---|---|---|---|
| 1950 July. Accrued Balance of income received from Executors of M. A. Nadarov ... | 79 | 14 | 11 |
| 1950 Aug. 31. Income tax to 1950 April refunded ... | 28 | 13 | 0 |
| 1950. Dividend, 3½ per cent War Stock ... ... ... | 8 | 14 | 11 |
| Dividend 3 per cent Savings Bonds ... ... | 3 | 1 | 3 |
| Dividend 3 per cent Savings Bonds ... ... | | 16 | 6 |
| | £121 | 0 | 7 |

| | £ | s. | d. |
|---|---|---|---|
| 1950 Dec. 31. Balance of Fund | 121 | 0 | 7 |
| | £121 | 0 | 7 |

**TRUST FUNDS**

*The Lee and Janson Fund* (1834 and 1879): In 1834 John Lee, Esq., LL.D., gave £100, and in 1879 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £309 16*s.* 3 per cent Savings Bonds, 1960/1970.

| | £ | s. | d. |
|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 101 | 0 | 2 |
| 1950. Dividends, 3 per cent Savings Bonds ... ... | 9 | 6 | 0 |
| Interest on P.O. Savings Bank Deposit ... ... ... | 1 | 0 | 0 |
| | £111 | 6 | 2 |

| | £ | s. | d. |
|---|---|---|---|
| 1950. Payment to Widow of a Fellow... ... ... ... | 10 | 10 | 0 |
| 1950 Dec. 31. Balance of Fund :— | | | |
| In P.O. Savings Bank ... ... £41 6 8 | | | |
| At Bank ... ... 59 9 6 | | | |
| | 100 | 16 | 2 |
| | £111 | 6 | 2 |

*The Turnor Fund and the Horrocks Memorial Fund* (1853 and 1876): In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £430 10*s.* 4*d.* 3 per cent Savings Bonds, 1960/1970. In 1876 the Society received a sum of £38 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55 15*s.*, and the whole now

stands in £95 13*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. The interest on these funds is to be used in the purchase of books for the library.

| | £ | *s.* | *d.* | | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | | 16 | 0 | 1950. Purchase of Books ... | 21 | 3 | 6 |
| 1950. Dividends, 3 per cent Savings Bonds ... ... | 15 | 15 | 8 | | | | |
| 1950 Dec. 31. Income of Fund over-expended ... ... | 4 | 11 | 10 | | | | |
| | £21 | 3 | 6 | | £21 | 3 | 6 |

*The Hannah Jackson (née Gwilt) Fund* (1861): In 1861 Mrs Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £287 3 per cent Savings Bonds, 1960/1970; the interest to be given in medals or other awards in accordance with the terms of the Trust.

| | £ | *s.* | *d.* | | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 14 | 0 | 3 | 1950 Dec. 31. Balance of Fund... | 22 | 12 | 3 |
| 1950. Dividends, 3 per cent Savings Bonds ... ... | 8 | 12 | 0 | | | | |
| | £22 | 12 | 3 | | £22 | 12 | 3 |

*The Harry Watson Memorial Fund* (1923): In 1920 Mrs Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542 18*s.* 2*d.* 3 per cent Savings Bonds, 1960/1970. In 1923 Mrs Watson bequeathed a further sum of £958 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

| | £ | *s.* | *d.* | | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 346 | 0 | 10 | 1950. Purchase of Books ... | 103 | 8 | 7 |
| 1950. Dividends, Agricultural Mortgage 4½ per cent ... | 23 | 17 | 10 | 1950 Dec. 31. Balance of Fund:— | | | |
| Dividends, 3 per cent Savings Bonds ... ... ... | 16 | 5 | 8 | In P.O. Savings Bank ... ... £264 9 10 | | | |
| Income Tax, 1949 April–1950 April, refunded ... ... | 19 | 10 | 8 | At Bank... ... 44 5 7 | | | |
| Interest on P.O. Savings Bank Deposit ... ... ... | 6 | 9 | 0 | | 308 | 15 | 5 |
| | £412 | 4 | 0 | | £412 | 4 | 0 |

*The George Darwin Lectureship Fund* (1926): In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

| | £ s. d. | | £ s. d. |
|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 115 1 6 | 1950 Oct. Lecture Fee ... | 50 0 0 |
| 1950. Dividends, Consolidated 4 per cent Loan ... ... | 40 3 2 | 1950 Dec. 31. Balance of Fund:— | |
| Interest on P.O. Savings Bank Deposit ... ... ... | 3 11 6 | In P.O. Savings Bank ... ... £146 16 7 | |
| | | *Less*: Temporary advance from "C" account 38 0 5 | |
| | | | 108 16 2 |
| | £158 16 2 | | £158 16 2 |

*The A. G. Stillhamer Trust* (1937): A. G. Stillhamer, Esq., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually* to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The bequest has been invested in £491 10*s*. War Stock 3½ per cent.

| | £ s. d. | | £ s. d. |
|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 223 17 4 | 1950 Dec. 31. Balance of Fund:— | |
| 1950. Dividends, War Stock 3½ per cent ... ... ... | 17 4 0 | In P.O. Savings Bank ... ... £110 13 4 | |
| Interest on P.O. Savings Bank Deposit ... ... ... | 2 14 0 | At Bank... ... 133 2 0 | |
| | | | 243 15 4 |
| | £243 15 4 | | £243 15 4 |

*The E. W. Brown Trust* (1939): E. W. Brown, Esq., M.A., Sc.D., F.R.S., who died in 1938, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160 16*s*. 3*d*. War Stock 3½ per cent.

| | £ s. d. | | £ s. d. |
|---|---|---|---|
| 1950 Jan. 1. Balance of Fund... | 207 9 9 | 1950 Dec. 31. Balance of Fund:— | |
| 1950. Dividends, War Stock 3½ per cent ... ... ... | 40 12 6 | In P.O. Savings Bank ... ... £195 14 0 | |
| Interest on P.O. Savings Bank Deposit ... ... ... | 4 15 6 | At Bank ... 57 3 9 | |
| | | | 252 17 9 |
| | £252 17 9 | | £252 17 9 |

* Miss Capps, subsequently to the initial conditions of the Trust, agreed to the income not being expended annually.

*The Plummer Bequest* (1946): H. C. Plummer, Esq., M.A., F.R.S., bequeathed to the Society the sum of £1000, to be invested and treated as a Trust Fund, the income to be at the disposal of the Council for all purposes, with a recommendation that they should consider the possibility from time to time of helping the Norman Lockyer Observatory. The Society was also named as one of the residuary legatees. In 1947 October, a first distribution, under the terms of the will, of £1500 was received from the Administrators of the Estate, which has been invested in £1471 4*s.* 0*d.* 3 per cent Savings Bonds, 1955/1965; this sum and any subsequent sum or sums which may be received from the Administrators will be used in accordance with the late Professor Plummer's wishes.

| | £ | *s.* | *d.* | | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|---|
| 1950 Jan. 1. Balance of Fund ... | 88 | 5 | 4 | 1950 Dec. 31. Balance of Fund. | 132 | 8 | 0 |
| 1950. Dividends, 3 per cent Savings Bonds ... ... | 44 | 2 | 8 | | | | |
| | £132 | 8 | 0 | | £132 | 8 | 0 |

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS (OTHER THAN BY EXCHANGE) TO THE LIBRARY DURING THE YEAR 1950.

The Admiralty
H.M. Air Ministry
Academy of Sciences, U.S.S.R.
Argentina, Instituto Geografica Militar
Association Française d'Observateurs d'Etoiles Variables
Astronomical Society of Mexico
Astronomical Society of South Africa
Astronomical Society of Tasmania
Board of Trade, Technical Information and Documents Unit
British Association for the Advancement of Science
British Astronomical Association
British Council
British Interplanetary Society
British Society for the History of Science
Copenhagen, Nordisk Astronomisk Selskab
Geological Survey of Ireland
Ghent, Sterrenkundig Instituut der Universiteit
Griffith Observatory, Los Angeles
Harvard University Committee on Geophysical Research
Imperial Chemical Industries
International Astronomical Union
International Hydrographic Bureau
International Union of Geodesy and Geophysics
Institute of Navigation
Institution of Civil Engineers
Lima, Sociedad do Ingenieros del Peru
Lisbon, Sindicato Nacional dos Engenheiros Geografos
London, Institute of Physics

Los Angeles, Astronomical Department, University of California
Lourenço Marques, Technical Statistical Department
Manila Observatory, Philippines
Mathematical and Physical Society of Egypt
Michigan University, Engineering Research Institute
H.M. Meteorological Office
H.M. Nautical Almanac Office
National Research Council of Japan
New York, Academy of Sciences
Princeton University
The Radcliffe Trust
Rome, Reale Accademia d'Italia
Royal Society
San Miguel, Observatoria de fisica Cosmica
Santiago Astronomical Observatory
The Science Museum
Service de Prévision Ionosphérique Marine
Sproul Observatory
Survey of India, Office of the Geodetic Branch
Trieste, Instituto Geofisico
Union Radio Scientifique Internationale
United Nations Educational, Scientific and Cultural Organization
Washington, Carnegie Institution
Washington, National Bureau of Standards

Dr H. Alfvén
Dr A. Armitage
Dr P. ten Bruggencate
Mr P. Couderc
Mr P. Doig
Professor Y. Hagihara
Mr A. W. Haslett
Professor O. Heckmann
Professor H. Jeffreys
Mr O. J. Lee
Professor W. H. McCrea
Professor M. G. J. Minnaert
Dr R. Müller
Mr M. Nicolet
Mr H. W. Robinson
Professor W. M. Smart
Mr D. H. Sadler
Professor A. Unsöld
Dr G. de Vaucouleurs
Dr G. Walén
Mr H. P. Wilkins
Professor E. Zinner

## OBITUARY NOTICES

THERALANDOOR PANCHAPAGESA BHASKARAN was born on 1889 April 12 in a small village, Tiruvadamaruthur, of Madras Presidency. He died at Begumpet, Hyderabad, on 1950 June 26. Three sons and three daughters survive him. Soon after graduation from the Madras University, he joined the service of the Nizamiah Observatory in 1912 as an Assistant. He worked in this capacity under the first two Directors, Mr A. B. Chatwood and Mr R. J. Pocock. After the death of Mr Pocock, he was in charge of the observatory for some time and became its Director in 1922. He retired on pension after a full service of 32 years. He was later reappointed for two years as Research Professor of Astronomy in the Osmania University.

Under his enthusiastic direction, the Carte-du-Ciel programme for the Astrographic Zones $-19°$ to $-23°$ and $+36°$ to $+39°$ was completed. Bhaskaran was mostly a practical astronomer. The 15-inch Grubb refractor of the observatory was erected under his supervision in 1922. He initiated a programme of observations of variable stars with faint minima with this instrument. The results of his various investigations appeared in more than 60 papers in several astronomical journals.

Besides astronomy, he was also keenly interested in meteorology and seismology. It was due to his practical interest in these sciences that the Nizamiah Observatory soon became a first-class weather and seismological station in India.

He was elected a Fellow of the Royal Astronomical Society on 1919 February 14. He was a foundation Fellow of the National Institute of Science, Calcutta and the Indian Academy of Sciences, Bangalore. He presided over the Mathematics Section of the Ninth Indian Science Congress in 1922.

The title of Rao Sahib was conferred on him by the Viceroy of India in 1940 in recognition of his public services. He was a very active Freemason.

Indian astronomy has suffered a great loss by his death.

A. ALI.

ARTHUR BURNET, whose death occurred on 1950 July 4, came of a family who for several generations had lived in Lincolnshire, occupying one farm for some 300 years.

He was born in 1879 and inherited the studious habits of his parents. After leaving school he entered his father's business, that of a joiner and timber dealer. He early displayed a keen interest in astronomy, especially in the prediction of occultations. After some three years of active service in the first world war, he went to Oxford Observatory under Professor Turner, and assisted Mr Bellamy in obtaining plates for the *Astrographic Catalogue*. The experience so gained proved valuable later on, and between 1934 and 1938 he measured a number of plates for the Potsdam zones of the Catalogue. After leaving Oxford he was of great assistance to the present writer in the photography of novae fields, and in the compilation of references to novae in scientific literature.

During the second world war he was engaged on work connected with long-range weather forecasting at the Meteorological Office.

Perhaps Burnet was best known in the astronomical world through his work on occultations; his results were published and referred to in a number of journals, some appeared in the *Monthly Notices*, others in the *Journal* of the B.A.A. and in the *Handbook*. Dr L. J. Comrie, in a Thesis on "Occultations of Stars by Planets" in 1923, referred to Arthur Burnet as having more predictions to his credit than anyone else, and stated that "he began in 1910 by sending a modest letter to *Nature* pointing out an occultation of Eta Geminorum by Venus". Dr Comrie went on to say, "Burnet's contribution to this subject has been a very valuable one". In almost the same words, Mr Sadler, the Superintendent of the Nautical Almanac Office, wrote in 1942, "in this work he has played a leading part for thirty years, and has certainly been responsible for more predictions than anyone else". Mr Sadler added, "Perhaps the most important aspect of his work, from the point of view of astronomy, lies in the fact that his predictions have resulted, not only directly in many valuable observations, but indirectly in drawing attention to, and inspiring interest in these phenomena, which have been long ignored".

He was for some years Hon. Secretary of the Leeds Astronomical Society and later an active member of the Newcastle Society.

Burnet's scientific interests were not confined to astronomy. He was an enthusiastic student of geology, devoting his attention particularly to the chalk of Yorkshire and Lincolnshire, in which field he was regarded as a high authority. He wrote several papers on this and other geological subjects in the early part of the century. These contributions were published in the *Geological Magazine*, *Transactions of the Leeds Geological Association* and elsewhere. In the last-named publication, he wrote on "Deep Sea Deposits, Ancient and Modern", "Neolithic Flakes from Lincolnshire" and the "Microscopic Aspect of some Cretaceous Rocks".

Arthur Burnet was a devoted adherent to the Methodist tradition of his forbears, and earned sincere gratitude by his ever-ready willingness to impart to others the results, not only of his scientific studies but also of his views on theological matters in which he was deeply interested. He was never married, but is survived by a devoted sister, who for many years of his later life shared his lot.

His sensitive temperament may perhaps sometimes have been misunderstood; all, however, who knew him well must accord their appreciation of one who, with few opportunities and no academic training, made so many worthy contributions to natural knowledge. He was elected a Fellow on 1921 March 11.

WILFRED HALL.

CHARLES JOHN PHILIP CAVE, who died at his home near Petersfield on 1950 December 8 in his eightieth year, was a man of widely varied interests and made a name for himself in both scientific and antiquarian pursuits. He was educated at the Oratory School, Edgbaston, and Trinity College, Cambridge. As a young graduate possessed of ample means and leisure he had felt an urge to promote, so far as lay in his power, the study of a branch of physical science which was then in rather low water—meteorology. His opportunity came in 1903, when Dr W. N. Shaw (later Sir Napier Shaw), at that time Secretary to the Meteorological Council and afterwards Director of the Meteorological Office, asked for volunteer collaborators in exploring the winds of the upper

atmosphere. Cave's offer of his services was welcomed and he set to work at once. Originally he used large kites flown on lengths of strong wire, but he soon adopted the more satisfactory method of measuring, by means of special theodolites sited at either end of a two-mile baseline, the angular altitude and azimuth of hydrogen-filled pilot balloons from minute to minute. In his first book, *The Structure of the Atmosphere in Clear Weather*, published through the Cambridge University Press in 1912, he presented an exhaustive summary of these investigations, which added materially to existing meteorological knowledge. During the 1914-18 war he served in England and France as instructor, experimenter and forecaster with the Meteorological Section of the Royal Engineers, holding the rank of captain. In 1915 he installed at the branch Meteorological Office near Aldershot a coherer lightning recorder of the Fenyi type, with the aim of warning aircraft pilots of approaching thunderstorms. This instrument, supplemented at Dr R. Whiddington's suggestion by a radiogoniometer, gave Britain the lead over all other nations in the field of meteorological study concerned with the location of atmospheric electrical disturbances at a distance—a field now known in official parlance by the unfortunate name of " sferics ".

Cave joined the Royal Meteorological Society in 1899 and was twice (1913–15 and 1924–26) its president. From youth he had shown himself to be a skilled technician and artist with the camera. As his interest in meteorology grew, he put this aptitude to such good use that his reputation as a photographer of clouds soon extended far beyond his native land. He contributed a number of the finest prints reproduced in the most recent (1932) issue of the *International Cloud Atlas*. Incidentally, he was responsible for rendering into English the original French text of this work.

Although his enthusiasm for meteorology never lapsed, Cave in later life became increasingly engrossed in antiquarian matters. Here too his prowess with the camera stood him in good stead. For many years he concentrated on the recording by telephotography of the hitherto little-studied roof carvings in medieval English cathedrals and churches—a subject on which he came to be regarded as a leading authority. In the course of this work he took over 8000 photographs.

Astronomy first claimed Cave's attention on its navigational side, for he was a keen and roving yachtsman. Subsequently the science drew him more and more for its own sake, as must almost inevitably happen to any constant watcher of the clouds, and on 1918 January 11 he was elected a Fellow of the Society. His published writings include a set of useful hints to pictorial artists for avoiding elementary astronomical blunders. One of his last major pieces of work was to measure the orientation of 642 churches : only 103 of these, he found, were positioned approximately on the true east–west line, while several lay fully 40° wide of the mark. Cave's report on this study, with a suggested explanation for the vagaries observed, appears in the 1950 January–April issue of the *Antiquaries Journal*.

E. L. HAWKE.

HENRY REGINALD FRY was elected a Fellow of the Society on 1919 April 11. By his death the Society has lost a Fellow who, through his interest in observing the heavens and his great generosity, has helped to provide the means

whereby some hundreds of young folk have viewed, and long may continue to view, celestial objects at the University of London Observatory.

Soon after the opening of the observatory in 1929, Mr Fry offered it his 8-inch equatorial refractor and 5-inch (unmounted) refractor, both by Cooke. The former was housed in the Fry Observatory, where it is in constant use for instruction of students of the University and also, in a more general way, for the pleasure and instruction of members of schools, colleges and clubs, and also residents of the district who apply for a " visiting night " invitation. The 5-inch refractor is mounted on the Radcliffe telescope in place of its original large " finder " which went to Pretoria.

Mr Fry took a science degree at King's College, Cambridge and then, for thirty years, was partner and director of Barclay and Fry, Ltd., printers and tin-box makers. He was a very able amateur engineer, and made a number of clocks, cutting the gear wheels in his own workshop. Shortly before his death he was admitted to the Worshipful Company of Clockmakers, and he left to his nephew, Mr Cecil Fry of Bristol, a fine collection of precision clocks.

C. C. L. GREGORY.

JOHN CHARLES WILLIAM HERSCHEL, elder son of Sir William James Herschel, second baronet, was born in Bengal on 1869 May 22. He was educated at Winchester and Christ Church, Oxford, where he took his degree in 1892. For a time he thought of adopting astronomy as a profession and, with this end in view, entered St. John's College, Cambridge, and became a research student at the University Observatory. Later, however, he abandoned his original intention and, following a few years spent in the study of practical engineering, eventually decided to enter the Church. After training at Wells Theological College, he was ordained in 1906 and subsequently held curacies at Bracknell, Berks, and elsewhere. From 1919 to 1934 he was Rector of West Clandon, Surrey, and then spent five years in Cornwall as Vicar of Perranzabuloe. His last benefice was that of Westbury, Buckinghamshire, and he finally retired from regular parochial work in 1945, although he continued to give occasional help to the local clergy. He died in the old home of the Herschel family, Observatory House, Slough, on 1950 June 15.

Although he scarcely considered himself seriously as an astronomer, Herschel did, in fact, contribute three papers to the Society during the time when he was at Cambridge—two on observations of meteors and one on photographic star-counts; and he always maintained a lively interest in the progress and developments of the science. From time to time he presented to the Society some valuable manuscripts and relics connected with his grandfather and great-grandfather, including the oil painting of the latter, our first President, which hangs in the meeting-room.

Modest with regard to his own attainments, he had a proper appreciation of the greatness of the family name and was always kindly and courteous in his manner to those who showed a like veneration for the work of his illustrious forbears. His friends will remember him as a man of unaffected goodness and sincerity.

He married, in 1908, Catherine Margaret, youngest daughter of the late Colonel E. T. Browell. She survives him, but there were no children of the marriage.

In 1917 Herschel succeeded his father in the baronetcy, which now becomes extinct, his younger brother Arthur having died in 1924.

He was elected a Fellow of the Society on 1901 January 11.

W. H. STEAVENSON.

FRANK HOPE-JONES, who died at his house in Richmond on 1950 April 3 in his 83rd year, was well known in the horological world for the inventive genius he displayed in the application of electricity to horology.

The youngest of a family of nine children, he was only five years old when his father died. The changed circumstances compelled the family to move from Hooton to a smaller house in Birkenhead. After a period of schooling at the Birkenhead Proprietary School, he was apprenticed with the Thames and Mersey Insurance Company, but he was soon taken from this post to assist an elder brother, Robert, some eight years his senior, who had founded the Hope-Jones Organ Company. Robert was a clever inventor but was so unbusinesslike that before long the Company was on the rocks, and in 1899 it went into liquidation. An employee in the organ workshop, George B. Bowell, had ideas of applying electromagnetism to clocks and had found a kindred spirit in Frank Hope-Jones. They had together designed and made an electric clock, their first joint patent having been taken out in 1895. What is now known as the Synchronome Switch was applied by them to an old French skeleton clock ; this first clock is now exhibited in the Science Museum as a milestone of horological history.

In 1897 Hope-Jones and Bowell formed the Synchronome Syndicate Ltd., the word Synchronome having been suggested by another elder brother, Kenyon, who was a classical scholar. After Bowell left the Syndicate, it went into voluntary liquidation in 1901; Hope-Jones took over the assets, carried on alone as the Synchronome Company Ltd., and brought the Company through to success, retiring from it in 1940. His numerous inventions were an important contribution to electrical timekeeping, and he was constantly preaching the principles essential to accurate timekeeping.

In 1910 at a meeting at the Institution of Electrical Engineers, at which Hope-Jones described the Synchronome System, he first met W. H. Shortt, who became interested in horology in that year and started the experimental work which eventually led to his development of the well-known Shortt free pendulum and of the " hit-and-miss " synchronizer, the slave clock being a commercial synchronome electric clock. The Synchronome Co. undertook the manufacture of the Shortt free-pendulum clocks, which soon became the standard timekeepers in many observatories of the world.

In 1931 Hope-Jones published his *Electric Clocks*, which was revised, enlarged and brought up to date and republished in 1940 under the title *Electrical Timekeeping*. It is a standard work of reference on this subject, and has been reprinted several times.

The proposal for a daylight-saving scheme was first launched by William Willett in a lecture to the British Horological Institute in 1907. Hope-Jones was present at the lecture and gave the scheme his immediate support. In articles, public lectures, and letters to the press he campaigned vigorously for the scheme, and he gave evidence before the Parliamentary Committee on the subject. The scheme was, however, first adopted in Germany in World War I, the United Kingdom following on 1916 May 20, after Willett had died.

Hope-Jones took an early interest in radio and particularly in its usefulness for the distribution of time-signals. After the distribution of time-signals from the Eiffel Tower had commenced in 1913, he produced a simple receiver to enable watchmakers to receive these signals and so to have correct time. This brought him into conflict with the Post Office, and eventually it was agreed that clockmakers could receive the time-signals on payment of a licence fee of one guinea a year. For many years he was Chairman of the Wireless Society.

The proposal that the British Broadcasting Corporation should distribute each day time-signals from the Royal Observatory, Greenwich, originated with Hope-Jones. In a broadcast on daylight saving from the old Savoy Hill station (2LO) on 1923 April 21, he had counted out from his watch, which he had previously set to G.M.T., the five seconds ending at 10 p.m. This practice was followed by some of the announcers, who did not always have the correct time available. It was at the suggestion of Hope-Jones that Sir Frank Dyson was brought into contact with the B.B.C., as a consequence of which arrangements were made for the broadcasting of the now familiar " six-pips " Greenwich time-signals.

In 1917 Hope-Jones married Florence Mary Pippett, who survives him with a daughter. He was awarded the Gold Medal of the British Horological Institute in 1946 for his contributions to horology. He was elected a Fellow of the Society on 1940 January 12.

H. SPENCER JONES.

GEORGE HENRY LIVENS was born in Watford on 1886 October 10, the second son of Henry John Livens, an artist by profession. He died in Cardiff on 1950 March 26. He was educated at Latymer Upper School, Hammersmith, and at Jesus College, Cambridge. In Part I of the Mathematical Tripos, 1909 (the last with order of merit, under the Old Regulations), he was bracketed 4th Wrangler and in Part II, 1910, he was placed in Division 2 of Class I (no candidates being placed in Division 1). In 1911 he was awarded first Smith's Prize and was elected a Fellow of his College.

He left Cambridge shortly afterwards to take up an appointment as Lecturer in Mathematics at Sheffield University; in 1919 he was appointed Senior Lecturer in Mathematics at Manchester University. In 1922 he was elected Professor of Mathematics at the University College of South Wales and Monmouthshire, Cardiff, a post which he held until his death.

While at Cambridge, Livens had been greatly influenced by Sir Joseph Larmor's lectures. He regarded the Faraday–Maxwell theory of electricity, generalized and extended to the case of moving systems by Larmor, as the most satisfactory form of the theory, because of its mathematical and physical consistency, and its generality. In 1918 he published a comprehensive text-book on *The Theory of Electricity*, developed from this point of view, which though mathematical in formulation emphasized throughout the underlying physical principles. He published various papers, mainly on the theories of electricity and magnetism and on thermodynamics. It is, however, as an inspiring and successful teacher of mathematics that he will be mainly remembered. His teaching was based on fundamental principles, his students were taught to think for themselves, and during his tenure of the Chair at Cardiff he built up a strong department of mathematics.

Livens took a prominent part in the general administration of the University and was much interested in student problems. For many years he was a member of the house committee of the Students' Union, where his wise counsel was much valued. As adviser and examiner in mathematics to the Central Welsh Board, he exercised a great influence on the teaching of mathematics in secondary schools; he also took a great interest in the mathematical courses in the Welsh Training College for Teachers. For many years he was an examiner in mathematics for the University of London.

He is survived by a widow, a daughter and a son. He was elected a Fellow on 1924 February 8.

H. SPENCER JONES.

TAKEHIKO MATUKUMA, a professor of the Tohoku University at Sendai, died suddenly on 1950 January 14.

He was born on 1890 March 18 at Karatsu in Saga prefecture, Japan. He finished the course of astronomy in the Tokyo University in 1913, but as there was no position vacant in astronomy he taught for several years at High Schools and in 1920 he was first appointed an assistant professor in the Tokyo University. In 1924 he changed to the Tohoku University and was made a professor of astronomy in 1934. From 1925 to 1927 he stayed in Europe and was present at the Cambridge meeting of the I.A.U.

Professor Matukuma's researches were mainly in the problem of three bodies and in relativity theory. In his later years he was eagerly engaged in the mathematical problems associated with the Schmidt camera. He liked travel and observed the solar eclipses in 1936 at Hokkaido, in 1941 at Paicho, China, and in 1943 at Hokkaido. At the 1941 eclipse he tried to verify the Einstein shift of stellar images and was successful. In addition he was a skilful teacher and published several lectures in book form. He was elected a Fellow on 1926 January 8.

Y. HAGIHARA.

EDWARD ARTHUR MILNE was born at Hull on 1896 February 14. He was the eldest of the three sons of Sidney Arthur Milne, headmaster of St. Mary's Church of England School, Salthouse Lane, Hull. The family lived at Hessle, where Milne began his education at the National School. Afterward he went to Hymer's College, Hull, where the headmaster, C. H. Gore, himself a gifted mathematician, inspired Milne's love of his subject as a schoolboy. Milne remained on terms of affectionate friendship with him for the rest of his life.

In 1914 Milne entered Trinity College, Cambridge, as a mathematical scholar. He spoke in later years of the wonderful sense of intellectual emancipation which he there experienced. No doubt his experience was a common one of young men entering the life of a great college and university. But, being constituted as he was, Milne must have savoured it with an intense awareness far above the average. He could see vistas of intellectual achievement stretching out before him, and it is small wonder that he always preserved a special regard for those who at that time directed his gaze in such directions. Among these he used to name particularly his director of studies E. W. Barnes, S. Chapman and G. H. Hardy.

The First World War had started when Milne went up to Cambridge, and, despite all his academic aspirations, he was anxious to serve in any way open

to him. His defective eyesight excluded him from active military service. He therefore eagerly accepted the invitation of A. V. Hill early in 1916 to join the Anti-Aircraft Experimental Section (as it was afterwards called) of the Munitions Inventions Department which Sir Horace Darwin had asked Hill to form. He forthwith became, in Professor Hill's words, " an essential element in our party and did some of the finest work we achieved ". The party came in course of time to include a big proportion of the most able mathematicians in the country as well as several distinguished physicists.

In obituary notices of R. H. Fowler (*Obit. Notices, Roy. Soc.*, **5**, 61, 1945–8; *M.N.*, **105**, 80, 1945) and of H. W. Richmond (*Obit. Notices, Roy. Soc.*, **6**, 219, 1948–9), Milne himself has recorded a vivid impression of the A.A. Section and of the atmosphere in which it worked. No other account could show so well, as the incidental indications he there presents, what effect those years had in developing his powers of mind and personality and in determining the trend of his interests.

The work was mainly on ballistics and sound-ranging; both subjects naturally involve many problems concerning the Earth's atmosphere, and this fact was probably the start of Milne's interest in atmospheric theory in general. He shared in the mathematical, computational and practical parts of the work, displaying great capacity in all of them. During gun trials, he was sometimes sent up in an aircraft as high as it would go to measure pressure and temperature at various heights; he had a talent for getting the R.F.C. pilots to do what was wanted. So as to ensure against his being conscripted and transferred from this sphere of service, he was commissioned as a Lieutenant, R.N.V.R. He worked mainly at Whale Island, Portsmouth, but spent some months in France with the Officer commanding the Anti-Aircraft Artillery of the First Army, who found Milne's assistance most valuable. For his war service he was awarded the M.B.E.

At the end of the war Milne wrote a volume on sound-location as one of three text-books asked for from the Section by the War Office. There also resulted from his war-work his first published paper (with R. H. Fowler) on " Siren harmonics and a pure tone siren ", *Proc. Roy. Soc.* A, **98**, 414, 1920.

In 1919 Milne returned to Cambridge and was forthwith elected a Fellow of Trinity College largely on the strength of reports by his war-time superiors. In the following year he accepted the invitation of H. F. Newall to become Assistant Director of the Solar Physics Observatory: it was this step that made him an " astronomer ", in a very broad sense of this term, for the rest of his career. From 1921 to 1925 he was University Lecturer in Astrophysics. In 1924 he was appointed also to a lectureship in Mathematics at Trinity College and resigned his post at the Observatory. His lectures were clear and stimulating and he took an exceptional interest in undergraduates who attended them and in those who had him for their director of studies.

From 1925 to 1928 Milne was Beyer Professor of Applied Mathematics in the University of Manchester in succession to his close friend S. Chapman. He was very happy in this position and put his heart and soul into his work. He entered fully into the academic, scientific and administrative activities of the university and earned the highest esteem of his colleagues and students. Many lasting friendships resulted from this intercourse.

In 1928 Milne was elected first holder of the Rouse Ball Professorship of Mathematics at Oxford and in 1929 to a Fellowship at Wadham College.

He retained these positions for the rest of his life. In a separate part of this notice Professor H. H. Plaskett gives an account of his time at Oxford.

During the Second World War, from 1939 to 1944, Milne had leave of absence from Oxford to serve with the Ordnance Board, working for the most part at Chislehurst, Kent. His work dealt with ballistics, the analysis of armour-piercing experiments, rockets, sound-ranging, and the optimum distribution of A.A. guns. To a considerable extent, it was a natural resumption of the work he did in the First War. His theoretical work on stability of projectiles and on armour piercing is still regarded as the latest achievement in these subjects. Once again his astonishing range of abilities made a deep impression upon all those with whom he worked.

Milne was twice married. His first wife whom he married in 1928 was Margaret (" Margot ") Scott, daughter of H. F. Campbell of Dornoch and niece of Professor E. Fiddes of Manchester. There were two daughters and a son of this marriage. Soon after the son's birth in 1938, Margot Milne died in exceedingly distressing circumstances. Milne's second wife was Beatrice Brevoort, daughter of the late William W. Renwick of Short Hills, N.J. She was an American whom he had me on board ship on the Atlantic just before the war and who, after the outbreak of war, made a heroic journey to this country for their marriage in 1940. They had a daughter born in 1943. In 1944 they moved back to Oxford, but during the course of their removal their war-time home near Chislehurst was destroyed by a flying bomb. This climax to the rigours of the war years in a strange country overstrained Beatrice Milne's gallant spirit and led to her tragic death in 1945.

In other respects, too, Milne's life was singularly overclouded by tragedy. His father died suddenly in 1921 at the age of 53 and left him to help to support his family. In 1923 he suffered an attack of epidemic encephalitis, a disease which made only a temporary appearance in England about that time. He was looked after by W. Hartree (father of D. R. Hartree), and other Cambridge friends helped to see that he got the best possible attention. Though he made a good recovery he did not escape the late after-effects which gave rise from about 1945 to nervous disturbances producing rigidity of muscles and tremor. Added to this, his heart became affected and for some years he was a sick man. He died suddenly in Dublin, where he had gone to attend the special meeting of the Society, on 1950 September 21.

Milne received many honours in recognition of his scientific achievements. They included the following awards and appointments: 1922 Smith's Prize; 1926 F.R.S.; 1929 Bakerian Lectureship, Royal Society; 1935 Gold Medal, R.A.S.; 1937–9 President of London Mathematical Society; 1934 Hon. D.Sc. University of Amsterdam; 1941 Royal Medal, Royal Society; 1943–5 President of R.A.S.; 1943 James Scott Prize, Royal Society of Edinburgh; 1945 Bruce Medal, Astronomical Society of the Pacific; 1946 Hopkins Prize, Cambridge Philosophical Society.

In appearance, Milne was small and slight, but, so long as his health remained, he could be said positively to exude vitality. His features were often set in intense concentration but in conversation they became wonderfully

mobile and expressive. They became overspread with impish delight at any witticism that appealed to him.

In personality, he was extraordinarily richly and completely endowed. He had a phenomenal gift for making and keeping friends of all ages. His friendships played a great part in his life: they were maintained by his natural loyalty as well as by his punctiliousness in correspondence and, above all, by his depth of human understanding. Some measure of this can be gauged from the obituary notices he wrote about some of the men he had known, R. H. Fowler, G. H. Hardy, J. H. Jeans, A. E. H. Love, H. F. Newall, H. W. Richmond, in particular. Each of these notices was a masterpiece of its kind and they have come to be counted among his notable achievements. With all their insight and skill of expression, they were composed in very short times, with few aids to his memory, and, as it happened, often during air-raids or other difficult circumstances.

His loyalty and understanding extended not only to individuals but to any institution with which he was associated. He had a most perceptive appreciation of the traditions of each of them and exerted himself unsparingly in their support. He was always ready, too, to enjoy any sociabilities connected with them. Aided by " photographic " powers of observation and memory, he took delight in literature and in art, especially architecture upon which he showed himself very knowledgable, and also in natural scenery. All who are in a position to know will agree that, notwithstanding all his brilliance in so many directions, he was at his best as a devoted father among his own children.

Milne's courage and will-power were superb. The tragedies of his life could have befallen no more sensitive soul: he escaped no detail of their poignancy. Besides all this, it was his fate that much of his work should be of a controversial character while the satisfaction he could derive from what he did depended to an unusual degree upon its gaining sympathetic consideration by others. Nevertheless, distracted as he was by private grief and often disheartened by what he regarded as almost wanton misunderstanding of his ideas, he persevered with manful determination towards the objectives he set himself. He was essentially a religious man; faith and courage gained the victory in each succeeding struggle of his life.

In reflecting upon Milne's scientific work, certain personal characteristics have to be taken into account. His intellectual make-up was predominantly that of a mathematician. Early in his second year at Cambridge, G. H. Hardy described him as one of his very best pupils in pure mathematics, and it is usually thought that, had it not been for the war, he would have become a pure mathematician of the Hardy school. The present writer is inclined to think, however, that Milne's special satisfaction was in the power and generality and also in the " pattern " of pure mathematics rather than in refinements of mathematical analysis. These characteristics were always present in the mathematics he used for his own investigations. But in his kinematic relativity, for instance, he did not usually remark that his functions were assumed to be single-valued and to be restricted in other ways, as a more analytically minded mathematician would automatically have done.

Milne himself considered that there were gaps in his knowledge of routine elementary mathematics in consequence of his not having completed the course

for the Tripos at Cambridge. It is hard to see any evidence of this in his work. He was, of course, the first to admit that in compensation his war-work with A. V. Hill and R. H. Fowler had given him an unrivalled training in methods of research. In passing, one cannot help suggesting that the singular circumstances of his early career did, however, have a psychological effect which he did not realize. As a young undergraduate he went to work with men who were mostly " dons ", with all that that status denotes to the undergraduate. In his own subconscious mind, this distinction of status must have become artificially stabilized for the next three and a half years. Ever afterwards he seemed to retain traces of the undergraduate attitude towards other workers.

Milne probably wished to be regarded as neither a mathematician nor a scientist, in the senses in which these terms are commonly understood, but as a " natural philosopher ". At first he contented himself with taking certain of what he considered the principles of natural philosophy to guide him to what physical problems it seemed desirable and profitable for a mathematician to tackle and to the way he should set about them. It is significant that his inaugural lecture at Oxford (1929) was entitled " The Aims of Mathematical Physics " and his second Presidential Address to the Society " The Natural Philosophy of Stellar Structure ". At this stage in his work, if he shared the gratification of other scientists in accounting for any particular observed phenomenon it was from a somewhat different viewpoint from theirs. He liked to regard it as illustrating some general " theorems " of mathematical physics rather than as a solution of a particular puzzle. The challenge to him was not to solve the puzzle itself but to build up the system of theory which would naturally lead to the solution of some class of problems to which the particular one would be found to belong. At a later stage he tended to the view that a more direct application of " philosophical " principles could lead to the discovery of natural laws possessing a status superior to that of any hitherto known. However, he scarcely went so far in this direction as some of his critics supposed. I think it was his developing philosophical attitude that led him to devote the last fifteen years of his life to the development of kinematic relativity, rather than that his discoveries in this subject produced his philosophical attitude. He came to believe, as he said in a letter in 1942, " that philosophy is the summit of scientific endeavour and that, unless one makes for oneself a philosophy of the ultimate nature of reality, one's science is meaningless ". I think, however, that philosophy was for him, by definition, that which would supply him with what he called a " meaning " for his work. Multitudinous as were his endowments, I do not think that they included the power to grapple with the problems of professional philosophy.

Milne's work on astrophysics, which was largely completed by 1935, was of such a character that its definite contributions became rapidly assimilated in the subject. Given the necessary space, it would be a comparatively straightforward matter to estimate its value in the light of subsequent developments which have already taken place. His later work on kinematic relativity is much more difficult to assess. But he has left a full account of it and in due course its value will also become apparent. What it seems most vital to put on record here is the tremendous influence which he exerted during a long and eventful period in the development of modern astrophysics and cosmology. This was at first most widely due to his published papers rather than to his leadership

of any "school". From 1921 onwards these papers appeared in quick succession and ranged over a great extent of the rapidly developing scope of astrophysics. The very speed with which they must have been composed meant that they bore with them their author's zest for discovery. They were full of ideas and they inspired the conviction that here were subjects worthy of being studied and upon which there remained plenty of useful work to be done. It would be inappropriate here to give names, but one knows that many of those who are now in the forefront in astrophysical research are glad to acknowledge that their early enthusiasm was enlisted by Milne's writings. Somewhat later, he was able also to exert a more direct influence upon a succession of distinguished pupils at Oxford. Some of those whom he influenced in one way or another proceeded to obtain results of more permanent value than his own. However, their work would not have been done but for the stimulus he gave them. The history of astrophysics during the past twenty or thirty years would have been very different had it been denied the inspiration of Milne's own brilliant genius.

The first main phase of Milne's work was the one that is of greatest proved value. It dealt, broadly speaking, with "atmospheric" problems in astrophysics and was naturally concerned with the two main classes of problem that arise, those of the transfer of radiation through an atmosphere and those of the state of ionization of the atmospheric material. Milne made major contributions in both categories. But the general theory has of course to combine the results of both types of investigation and the combination produces its own problems concerning the detailed interaction of matter and radiation: Milne examined many of these with great thoroughness and elucidated many points of considerable subtlety.

The foundations of the theory of radiative transfer through a scattering atmosphere had been laid by A. Schuster in 1901 and those of the theory of an absorbing atmosphere in radiative equilibrium by K. Schwarzschild in 1905 and 1915. Milne's first undertaking was to recast, extend and combine their investigations and to provide approximative methods for solving the resulting equations of transfer. Part of this work he described in his first paper to the Society in 1921 and others following soon afterwards, but the main account is in his well-known paper in *Philosophical Transactions* 1922 (this itself being part of his Smith's Prize Essay). Amongst other results, he derived expressions for the emergent flux and the law of darkening towards the limb as functions of the frequency of radiation for an atmosphere in radiative and local thermodynamic equilibrium and in which the opacity depends on frequency. Milne showed that his work made it possible to use the observations of the continuous spectrum and limb-darkening for the Sun in order to infer the dependence of the opacity on frequency. His method is still employed to obtain this information and thus to provide the evidence for ascribing the opacity mainly to the negative hydrogen ion. In fact, as Professor Chandrasekhar has remarked to the writer, Milne might easily have predicted the existence of a constituent in the solar atmosphere possessing just those properties which we now know the hydrogen ion to possess.

For an admirable account of this phase of Milne's work one cannot do better than to refer to the address* delivered by Professor F. J. M. Stratton as

* F. J. M. Stratton, *M.N.*, **95**, 421, 1935.

President on the award to Milne of the Gold Medal " for his work on Radiative Equilibrium and the Theory of Stellar Atmospheres ". Professor Stratton dwelt deliberately upon the physical significance of the work but, as he indicated, it contains much that is of mathematical interest as well. Here it may suffice to allude only to one or two of the main achievements. Perhaps the greatest was that of the joint work of Fowler and Milne in 1923–4 on the intensities of lines in stellar spectra. They did not claim to add any new basic idea to those that had shortly before been contributed by M. N. Saha. But, by exploiting more powerful methods of statistical mechanics to obtain a theory of the maximum intensity in the spectral sequence of any particular line, instead of its marginal appearance, they obtained more trustworthy estimates of the temperatures and pressures in stellar atmospheres. More than any other single investigation, their work established the modern view of the orders of magnitude of these quantities.

This work was probably the most that could be achieved without employing a detailed theory of the formation of stellar spectral lines and dealing with the relevant problems of radiative transfer. Milne had all along played a leading part in the development of this side of the work, though by this time several others were also making important contributions. The culmination of his own contribution was his Bakerian Lecture of 1929.

By this time Milne had got the ideas that he thought would revolutionize the theory of stellar structure (the material of his paper read at the November meeting of the Society that year) and had set his heart upon announcing them to the world in his Bakerian Lecture. He had consulted Eddington whose instincts told him that Milne's conclusions could not be valid and who advised Milne to withhold the work for reconsideration for at least six months. With grave reluctance, Milne acquiesced and, only three or four weeks before the Lecture, resolved upon the subject he actually presented, " The structure and opacity of a stellar atmosphere ". Working at speed, he completed the extensive calculations required for the results as they stand in the published Lecture. The outcome was perhaps his most useful paper after that of 1922. He showed how the concept of the " concentration " of a particular atomic species in a stellar atmosphere, which had been used by Fowler and himself, could be replaced by that of the " number of atoms above the photosphere ", which could in turn be related to a precisely defined measure of the intensity of a line produced by them. He then showed how a comparison of the theoretical value of this intensity with observation would yield an absolute value for the continuous absorption coefficient of the atmosphere. He proceeded to give the first reliable quantitative theory of the absolute magnitude effect upon the line intensities. Finally he explored the physical state of the photospheric layers more extensively than ever before. In describing his results he acknowledges what the present writer remarked at the time, that they would require modification if the predominant abundance of hydrogen were substantiated. But the general concepts he introduced stimulated many of the most important subsequent developments.

In company with other astrophysicists at the time, Milne failed to understand how Eddington could (within fairly narrow limits) calculate the luminosity $L$

of a star of given mass $M$ without any knowledge of the source of the luminosity. It seemed to Milne that, in the absence of such knowledge, $M$ and $L$ had to be treated as independent variables, in fact that the fundamental problem of stellar constitution was, given material of any assigned mass $M$ capable of radiating at any assigned rate $L$, to calculate the equilibrium configuration of the resulting " star ". Then in 1929 he was seized with the conviction that he had discovered the flaw in Eddington's work, and, as a result, the way to solve the fundamental problem as he saw it. Since his preliminary calculations gave startlingly new conclusions about stellar structure—gaseous stars with radii of the order of a parsec, partially non-gaseous stars with central temperatures of the order of $10^{12}$ degrees, and so on—he naturally considered that he was on the threshold of the greatest things in his career and he went to work on them with consuming energy. During the next few years he published papers totalling some hundreds of printed pages and containing the results of tremendous efforts in computation, devoted to the development of these ideas.

Milne thought that Eddington had been led astray by making his results depend upon a singular solution of Emden's differential equation. When Milne realized that there are infinitely many other solutions he concluded that, in a general way, these must correspond to the existence of stars of all other luminosities besides the (almost) unique one that Eddington had singled out for consideration. He thought that Eddington had failed to discover these other possibilities as a result of having assumed the gas-laws to hold throughout, having integrated out from the centre and having used only approximately correct boundary conditions at the surface.

Milne argued that we can assume the gas-laws to apply only sufficiently near the surface, that it is necessary to integrate inwards from the surface, and that, since the mathematics then shows the impossibility of the gas-laws continuing to apply for general values of $M$, $L$, it is necessary to complete the model with zones of material obeying other equations of state. He proceeded to give elaborate discussions concerning the maximum amount of information about the internal structure of a star that can legitimately be inferred from comparisons with observation.

It may perhaps be said that Milne's approach was more logical but less scientific than Eddington's ! What Eddington had done was not, of course, to *assume* that the gas-laws hold good throughout any actual star, but to work out the properties of a gaseous model star of given mass $M$. He found that for this to be in equilibrium with any radius $R$ it must possess a certain luminosity $L$, which he found to depend only insensitively upon $R$. To his own surprise he found that his calculated value of $L$ (for any plausible value of $R$) agreed well with the observed value for all stars other than white dwarfs. But when he considered the internal conditions of his model as found from his calculations, he was able to show that matter must in fact be gaseous under these conditions. Eddington had therefore a self-consistent model that agreed satisfactorily with observation. He was justified in his belief that the mechanism of energy-generation would be found to be compatible with his results. For all that is required is that this mechanism should depend upon a high power of the temperature. The star can always then find a radius $R$ such that the rate of energy-generation balances the rate of emission $L$ from the surface, and this

value of $L$, as Eddington discovered, depends only weakly on the value of $R$. As we now know, thermonuclear processes of energy-generation do satisfy the requirement.

In retrospect, it is surprising that Milne did not see that his work actually strengthened Eddington's position. For Milne's more general approach made it possible explicitly to exclude cases not considered by Eddington.

One is referring here to Eddington's model in a generic sense. Obviously, a great deal has needed to be done since Eddington's own work. While it cannot be claimed that any of the subsequent advances were made by Milne himself, it is fair to assert that a number of them are due to his having either provided the stimulus or the required mathematical framework. And it may be added that he had himself reached a position in which he could have derived some of the results by merely reversing certain of his arguments.

In 1932 Milne proffered the suggestion that the physically obscure phenomenon of the " expansion of the universe " is perhaps not essentially different from the inevitable dispersal of, say, a gas-cloud liberated in free space. This simple observation was destined to divert his main interest from astrophysics to cosmology and relativity and to the consideration of the status of laws of nature.

Although it was demonstrated that the effect to which he had called attention is taken care of by general relativity, Milne was convinced that he had found a clue to an entirely new approach to cosmology. If the broad features of the expanding universe can be explained by elementary principles of pure kinematics, he argued, is it possible that *all* its properties result from its kinematics and nothing else ?

Despite Milne's assertions that no-one was more astonished than himself by subsequent developments, one must credit his audacious imagination with showing him from the start that something big could be expected of his venture. This proved to be the creation of " kinematic relativity ". Whatever its ultimate scientific value, as an intellectual creation of a single mind it is almost unique in character. For its main construction, Milne followed no traditions, borrowed no concepts, and found no ready-made mathematical machinery.

Briefly expressed, Milne constructed a theoretical model of the universe in which observers are endowed with specified rudimentary means of observation, the description of this universe being expressed entirely in terms of the observations made by them. As a consequence of his specification of the system, he showed that there exists (in a mathematical sense) a fundamental set of equivalent observers. Assuming the cosmological principle that each fundamental observer must see the same " world-picture ", he established many properties of this world-picture and certain properties of the motion of a free test-particle. From the latter he inferred, without further assumptions, that the phenomenon of gravitation is exhibited in his model and that it follows what can be interpreted as the inverse square law.

Milne then proceeded to develop systems of dynamics and electrodynamics. These were framed so as to be consistent with the foregoing work, but were otherwise of a rather formal character. His last paper, which he was to have read in Dublin, claims to show that his work predicts effects much like those resulting from Blackett's hypothesis concerning the magnetic fields of rotating masses.

The development of the work is recorded in a long series of papers; various aspects are reviewed in several of Milne's published addresses, including the first of his Presidential Addresses to the Society (1944); systematic accounts are given in his books *Relativity, Gravitation and World Structure* (1935) and *Kinematic Relativity* (1948). These are all pervaded by the sense of exhilaration which Milne experienced in his pursuit of the work.

Despite the stamp of inspiration borne by it, kinematic relativity has attracted comparatively little scientific interest and considerable adverse criticism. One owes it to Milne to make some attempt to analyse the reasons.

Kinematic relativity is an alternative to general relativity. Now general relativity as a theory of gravitation (i. e. ignoring electromagnetic phenomena) is generally considered to be highly satisfactory. We cannot, however, conceive that any theory is incapable of being improved upon. But the structure of general relativity is such that it admits of no *slight* re-adjustment. Therefore any possible improvement presumably demands a radically new approach.

Milne did make such an approach. Moreover, he made it in what ought to be the most promising way, for he worked directly in terms of "observables". In fact his analyses of timekeeping and related problems, along with the contributions of G. J. Whitrow, do seem to denote real progress in the treatment of space-time. This work has already led A. G. Walker to a far-reaching analysis of the foundation of relativity theory.

Such work, however, is apt not to attract much notice unless it has some novel physical consequences. Kinematic relativity has hitherto been somewhat unproductive of these. I believe this to be because, apart from the fundamental parts just mentioned, it depends upon the use of a strict cosmological principle. This was explicit in the earlier presentations but tended to become obscured in *Kinematic Relativity*. Now the universe manifestly does not conform strictly to a cosmological principle—at best it conforms only statistically. But a statistical property would not meet Milne's requirements as he developed the theory. Therefore it seems that kinematic relativity has been developed so as necessarily to yield not much more than the analogues of some of the particular models already treated by the general relativity theory of the expanding universe, and to be in its existing form incapable of dealing with more detailed problems, e. g. planetary orbits. Moreover, the analogues of the general relativity models are almost the same as the latter and this is one reason for the belief that the theory gives nothing of fresh physical interest. But this impression is not entirely justified. For Milne's fundamental particles (galaxies) may be regarded as a *discrete* set while the general relativity models represent a completely smoothed-out universe. Consequently such properties of the universe in the large as depend characteristically upon the discreteness of the galaxies cannot be revealed by the latter models but may to some extent be revealed by Milne's methods.

Much might be written about Milne's claims regarding the significance of his work. If there was an occasional hint of extravagance in them, it was only human and not to be derided by those of us who have adventured less in pioneering thought. It seems to the writer that an analysis of his claims shows that many of them were not essentially different from those made on behalf of any physical theory. The remainder seem to amount to saying that in his theory certain of the initial propositions (axioms) concern the observers instead of the system observed; this can be recognized as a progressive feature.

Besides the main lines of work already mentioned, Milne wrote extensively upon many other topics. These included the physics of the Earth's upper atmosphere (with S. Chapman, 1920), the escape of molecules from an atmosphere (1923), the chromosphere and the ejection of high-speed atoms from the Sun (1925–6), to mention only a few of the best-known and most frequently quoted investigations; problems in thermodynamics, statistical mechanics, pulsating stars, to give instances of his recurrent subsidiary interests. Also, besides the books already mentioned, he wrote " Thermodynamics of the Stars ", published as part of the *Handbuch der Astrophysik* (Berlin 1930), which is a very fine text-book of radiation theory, and *Vectorial Mechanics* (1948), a book whose value is becoming increasingly appreciated and is likely to establish itself as a minor classic. These illustrate Milne's unfailing mastery of orthodox applied mathematics, which was probably what stood him in such good stead in his two spells of war-work. Together with the evidence of his early work, they irresistibly suggest that his true genius lay in the most skilful mathematical handling of well-understood physical processes. Had he imposed more check upon an unacknowledged yearning after revolutionary concepts, he would probably have surpassed even the brilliant achievements that now stand to his credit. Milne wrote, too, a life of J. H. Jeans, which is still in the hands of the publishers. At the time of his death he had just completed *Modern Cosmology and the Christian Idea of God the Creator*, which was the text of an intended course of lectures on the Edward Cadbury Foundation in Birmingham.

He was elected a Fellow of the Society on 1921 February 11 and served on the Council 1923–27, 1928–34, 1935–39, 1943–48, being a Vice-President 1936–38, 1945–47 and President 1943–45.

The writer gratefully acknowledges much information (not all of which has there been space to include) about Professor Milne's life supplied by his brother Mr P. S. Milne, Professor E. D. Adrian, Sir Lawrence Bragg, Professor S. Chandrasekhar, Brigadier P. S. Gostling, Professor A. V. Hill, Professor L. J. Mordell, Professor F. J. M. Stratton and Dr G. J. Whitrow.

W. H. MCCREA.

Milne was elected to the newly founded Rouse Ball Professorship of Mathematics in 1928, and took up his appointment at the early age of 33. The other Professor of Applied Mathematics was A. E. H. Love, whose days of active research were then nearly over, though his lectures were still the most lucid, as they were among the most popular in the University. Milne's arrival, however, brought new life to the subject, and he soon attracted to himself some of the more able of the young mathematicians. His colloquium, an innovation in this subject at Oxford, was attended by these students and by many senior members of the University who found in Milne a stimulating leader with an unusual gift for seeing a subject in a new light. On a famous occasion Henry Norris Russell, in Oxford for the delivery of the Halley Lecture, read a paper on the advance in periastron of Y Cygni, and the ensuing discussion, which arose from the contrasting physical approach of Einstein and the mathematical insight of Milne, lasted late into the night. The measure of Milne's achievement at Oxford is to be found in the applied mathematicians

who took their doctorate under his supervision; these include Camm, Cillié, Cowling, Getting, Prasad, Walker and Whitrow, to mention only some.

Characteristically Milne entered fully into other sides of the life of the University and was at the same time a devoted Fellow of Wadham, the college to which his professorship was attached. He was of course a member of the Sub-Faculty of Mathematics, and for a number of years its chairman. In this capacity he played an important part in securing rooms for the Mathematical Institute in the newly opened wing of the Radcliffe Science Library, and won a hard-fought action to secure for mathematicians the right to smoke in these sacred precincts. He was almost continuously an official member of the Board of Faculty of Physical Sciences and for the last two years of his life its chairman. He was also a member of a somewhat dull body, the Museum Delegates, and conscientiously attended its every meeting twice in each term. He dined frequently and regularly in College, and of his life there it has been recorded that " he was anxious only to take his share of duties and responsibilities ". For some years after the war he was the College Librarian, and was responsible, almost single-handed, for cataloguing and re-arranging its books.

The appointment at Oxford coincided with a change in the direction of Milne's interests. Up to that time, as Professor McCrea has set forth so clearly, Milne had concentrated on the problems presented by stellar atmospheres. He was among the first to realize that the concept of radiative equilibrium entailed the constancy of the net flux of radiation through the atmosphere, he was the first to give the integral equation for this net flux, and he used its constancy to obtain a greatly improved approximation to the dependence of temperature on optical depth. In the second paper communicated by him to the Society he gave independently, and at the same time as B. Lindblad, the spectral distribution and the darkening to the limb which hold for a model solar atmosphere in radiative equilibrium with a grey coefficient of absorption, and showed how closely this prediction was obeyed by the Sun itself. In his Smith's Prize Essay he was the first to treat the inverse problem of finding the temperature distribution from the observed darkening to the limb, and gave a solution, commonly ascribed to R. Lundblad, who independently and slightly subsequently had reached the same result in a paper in the *Astrophysical Journal*. In this same Essay Milne also discussed the effect of simultaneous scattering and absorption in a stellar atmosphere, and gave the first solution of the Milne–Eddington equation of transfer, more usually applied to the formation of absorption lines. These and a great variety of related investigations were lucidly described in his *Handbuch* article " Thermodynamics of the Stars " —a work which is still standard and has formed the starting-point of the more elaborate modern investigations of Hopf, Chandrasekhar and Kourganoff. Milne had been among the first to recognize the revolutionary consequences of Saha's theory of thermal ionization, and as described by Professor McCrea, Fowler and Milne together applied this theory in a quantitative fashion to fix the temperature scale of the stellar spectral sequence. Arising from this work the two authors became interested in unit mechanisms and the principle of detailed balancing, and in a beautiful paper in the *Philosophical Magazine* Milne used this method to derive Saha's equation and to discuss the absorption coefficient in the Balmer and Lyman continuous spectra. Almost simultaneously appeared related papers on radiation pressure and chromospheric equilibrium,

and these led in turn to the concept of " run-away " atoms—a hypothesis still invoked in related solar and terrestrial phenomena.

With such a wealth of achievement behind and with so many fascinating problems opening before him, it may seem surprising that Milne should have abandoned stellar atmospheres. There is, however, some evidence that he was at no time greatly interested in the details of atomic physics, and felt himself increasingly out of touch with work in this field as quantum and wave mechanics developed. The loss of an almost daily contact with those Cambridge teachers and colleagues, whom he so greatly revered and who were in the thick of these developments, undoubtedly weakened his interest still further; at the same time it left him free to follow a natural bent in directions which, unlike the theory of stellar atmospheres, made no demands on a detailed knowledge of atomic physics. The new theme was set in his inaugural lecture; in it mathematical physics was elevated to an almost infallible method for the discovery of general principles and these were to transcend the physical experiments and the astronomical observations which had given mathematical physics birth. That there was some truth in this thesis, which he brilliantly defended, cannot be doubted, any more than it can be doubted that the genius of Rutherford, almost without mathematics, could unravel the complexities of radioactive transformations or deduce the nuclear structure of the atom. The fact is that the fruitful hypothesis, whether it be dictated occasionally by mathematical form and generality, or much more frequently by physical insight, is the philosopher's stone of physics, but to its discovery there is no royal road. This, however, Milne was not prepared to admit, and he continued to hope that from the mathematical situation alone great general principles might flow. Rarely in an inaugural lecture has a policy been so clearly defined, or so conscientiously followed.

For the keynotes of Milne's character were conscientiousness and severe self-discipline. He admitted no weakness in himself, and perhaps not unnaturally found it difficult to understand in others. Having set himself a task he could not be deflected, and the work he completed before, during and particularly after the war when he was broken in health and almost overwhelmed by personal tragedy must stand, if nothing else, as a monument to human endeavour. Driving himself to the last, with every task completed, he left on the journey to Dublin and died, as he had lived, undefeated.

H. H. PLASKETT.

WILLIAM HENRY OWSTON was born on 1875 October 15, being the son of William Owston of Fordon, Yorkshire. An engineer by profession, he was for many years employed at the Royal Arsenal, Woolwich. Afterwards in private business in Leeds and Newark, he later established himself in London, and when his office was destroyed in an air-raid he moved to Walsall. Though not a contributor to the *Monthly Notices*, he took a keen interest in the proceedings of the Society. He was a regular attendant at its meetings and made frequent use of the library and the facilities which exist for borrowing books. As a mark of his appreciation he defrayed the cost of purchasing a number of old and valuable books which it was thought desirable to add to the library. He was of a kindly and tolerant disposition and a genial companion. A few years ago he underwent a severe operation, and it was due to the devoted

attention of his wife that his life was spared. It was a great blow to him when, shortly after his recovery, she herself died, and he never really got well again. For the last three years of his life he was an invalid and he died on 1950 December 15. There are no children. He was elected a Fellow on 1931 April 10.

P. J. MELOTTE.

DHIRENDRA NATH SAHA at the age of 18 joined the Computing Office of the Survey of India at Dehra Dun in 1907, to serve under his father, Babu Shiv Nath, the Head Computer, then nearing retirement.

Although not high ranking, the computers of that office—in which a few decades earlier had been successfully carried out the simultaneous adjustment of the great Indian geodetic triangulation net, embracing an area greater than that of Europe less Russia—had a rather special and well-deserved standing. A few years later, probably 1912 when I had charge of that office, I remember Dhirendra Nath coming to me with a proposition that he should devote his due leave to a visit to Europe to widen his education. At the time this seemed an ambitious scheme, but I believe that it was carried out—I did not see him again—and led to advancement, first to the Upper Subordinate Service in 1914, and transfer to Burma. He served mostly in Burma or Assam in topographical surveying for the remainder of his career, until his retirement in 1944. Meantime he had been promoted to Class II Service in 1927 and he became a Fellow of the Royal Astronomical Society on 1930 March 14. In Burma he learned the Kachin language and he worked for 18 months in the hazardous area known as the " Triangle " where head-hunting was practised. Latterly he suffered ill-health. He died of heart failure on 1948 April 28 at Dehra Dun.

He leaves a son, who has completed an engineering course in England, and a daughter, still at school. His younger brother, Mr B. N. Saha, is the present Director, Southern Circle, Survey of India, at Bangalore.

I take pleasure in recording my high regard for the late Mr D. N. Saha as well as admiration for his enterprise.

J. DE GRAAFF-HUNTER.

ROLAND DALE THOMPSON died in tragic circumstances in a motor accident at Otahuhu on 1950 June 17. It is believed, however, that he died of heart failure while driving his car and thus causing the accident.

Born at Nelson on 1895 January 8, he was first educated at Nelson College where he was Dux in 1912. He then entered Victoria University College as an Entrance Scholar and subsequently graduated M.A. with Honours in Mathematics and Mathematical Physics, and B.Sc. He was also a Sir George Grey Scholar in Astronomy and Mathematics, a Senior Scholar in Mathematics, a Cook Memorial Prizeman, and a Jacob Joseph Research Scholar.

For some years Mr Thompson held temporary posts in the Government teaching service in New Zealand and as lecturer at Canterbury University College, Christchurch, and part-time lecturer at Victoria University College, Wellington. In 1920 he was appointed lecturer in Physical Science and Mathematics at the University of Western Australia, Perth, W.A. While in Western Australia he obtained his M.Sc. degree in astronomy, and was elected a Fellow of the Royal Astronomical Society on 1923 January 12, a Life Member of the Société Astronomique de France, and a Member of the Mathematical

Association, London, in the same year. He was an Associate Member of the Australian National Research Council, and Australasian Association for the Advancement of Science, and was Honorary Secretary to the Royal Society of Western Australia, 1923–28.

In 1928 Mr Thompson returned to New Zealand on account of ill-health. He subsequently held teaching posts at various secondary schools under the New Zealand Education Department, and at the time of his death was First Assistant Master at the Otahuhu College, Auckland, N.Z. He was also a Member and Past President of the Auckland Mathematical Association and the Auckland Astronomical Society.

One of his better-known contributions to astronomy was the computation of the circumstances of the total solar eclipse of 1922 September 21, together with a discussion on shadow bands. He also assisted the late Dr C. E. Adams in writing up the report of the New Zealand observations for the International Longitude Observations in 1926.

He was of a very retiring nature, which never revealed to the unobservant his knowledge, ability or attainments.

I. L. THOMSEN.

CHARLES JAMES WESTLAND was a lovable character and a great friend of all practical astronomers in New Zealand. Born in India at Nagpur in 1875, he was the son of Sir James Westland, Minister of Finance, in India.

He received his education at a preparatory school in England, and then went to Clifton. He spent a few terms at Christ's College. It was evident that he had developed a wide variety of tastes in the field of scholarship, but just how or when he became interested in science is not known. There was undoubtedly a deep-seated urge within Westland for scientific work, and he was a student and worker right to the end.

His parents came to New Zealand in 1891, and after leaving school he became a cadet at the Lake Coleridge Station. In a ballot for the Cheviot Estate he was fortunate in obtaining a section which he called "Glen Muick", and commenced life as a farmer. It was here that he commenced studying astronomy as a hobby. He married Ellenor Fisher, daughter of Captain Fisher of Beckenham.

In 1915 the late Dr C. E. Adams, Government Astronomer, went to the Lick Observatory to take up the Martin-Kellogg Fellowship, and Westland was appointed Acting Government Astronomer. Volunteering for the New Zealand Expeditionary Force he went to France as a signaller in 1916 and remained overseas for three years. On his return to New Zealand he was again Acting Government Astronomer for short periods in 1919 and 1920 during temporary absences of Dr Adams.

From 1921 to 1930 he was employed at the Apia Observatory variously as Assistant Director and Acting Director. Westland was one of those people who had his fair share of small observatory tribulations. Either with few or no assistants he would carry on working against odds to keep things going. When difficult times caused the Government to refuse to print seismological data, he bought a small printing set and laboriously printed his own bulletins. In the early years at Apia he came under the influence of Professor Angenheister and it is perhaps true to say that he absorbed a good deal of German methodology

which was evident for the rest of his life. He loved to write little German sentences in his letters.

Although he officially retired after leaving Apia, he was employed for two months as a seismologist at the Dominion Observatory in 1931. Here, again, his devotion to duty was demonstrated. Seeing the amount of work on hand requiring attention with only a small overworked staff to deal with it, he gave free voluntary service for an additional eight months.

In his retirement he revelled in making and reporting seismological observations and in astronomical computations. He became interested in orbit work and eclipses, and typed little books of his works which he distributed to his interested friends. The late Dr L. J. Comrie visited him on his last trip to New Zealand, and remarked " He is the Crommelin of New Zealand ".

With a twinkle in his eye, a brain as keen as a sabre, and a restless nature, Westland had to be met to be appreciated. In his later years, with failing health which he blamed on tropical service, he detested the restrictions which were placed on his movements. Had it not been for his interests one cannot predict how he would have managed.

After a short bout of influenza he passed away at Christchurch on 1950 July 11.

He became a Fellow of the Society on 1915 April 9.

I. L. THOMSEN.

## PROCEEDINGS OF OBSERVATORIES

### *Royal Greenwich Observatory*

*(Director, Sir Harold Spencer Jones, F.R.S., Astronomer Royal)*

*Meridian Department.*—The restricted programme of observations with the Airy transit-circle has been continued. During the year the following observations of members of the solar system were obtained :—

| | | | | | |
|---|---|---|---|---|---|
| Sun | 133 | Venus | 46 | Pallas | 14 |
| Moon | 82 | Other planets | 69 | Juno | 4 |
| Mercury | 6 | Ceres | 9 | Vesta | 5 |

One observation of Nova Lacertae III S.P. was secured. 1950 transits were obtained of standard stars for clock and azimuth error.

Observations were continued of the stars in the narrow belt around the Herstmonceux zenith for use with the photographic zenith telescope, together with stars from the FK3 catalogue contained in a wider belt, on which the P.Z.T. star places will be based. 1563 observations of P.Z.T. stars and 561 of FK3 stars were made.

The total numbers of transits and zenith distances secured with the instrument on these programmes were 4618 and 3303 respectively.

The improvement in the seeing of the reflected images of the spider webs during nadir observations with the Cooke reversible instrument, resulting from the new method of supporting the mercury bath above floor level from the piers, was such that it was decided to employ a similar arrangement for the Airy instrument. In addition, a simple lens of approximately 8½ inches focal length was mounted between the illuminating lamp and the eye-end of the instrument when pointed on the nadir, to direct a more convergent beam of light into the Bohnenberger eyepiece, as it had been found that the previous beam did not fill the objective. These two modifications have resulted in a much better-defined reflected image.

The object glass of the Cooke reversible transit-circle shows a great deal of coma at the edges of the field and, even within the limits of field normally used for observations, the coma is more than is desirable in fundamental meridian work. It will be replaced by a coma-free lens which has been ordered.

One of the collimators of the Cooke instrument, whose object glass is similar in aperture and focal length to the telescope itself, was set up on the site of the meridian group of buildings at Herstmonceux; azimuth marks in the form of illuminated pinholes were examined with it at distances of approximately 400 feet and 1200 feet respectively to decide whether the inferior seeing at the greater distance would outweigh the advantage of greater distance. Further observations will be made in the summer, when seeing conditions are at their worst, before a final decision is made.

It has been decided to convert the microscope micrometers of the Cooke instrument to photographic recording; preliminary enquiries have been made of a firm with the necessary facilities to undertake the construction of the apparatus.

The department lost the services of two old-established members with the retirement of Mr H. W. Acton on March 31 after forty-six years in the Observatory, and of Mr R. T. Cullen, at the end of the year, after nearly fifty years in the Observatory, during the last sixteen of which he was in charge of the meridian work.

*Astrometry and Astrophysics Department.*—Measured positions for all the catalogue stars in the Cape Zone $-56°$ to $-60°$ have now been reduced to the Cape system of meridian places, which is linked with FK3. Positional corrections, derived from an analysis of the residuals shown by the reference stars, have been applied over the whole zone by means of a flexible graphical method which takes account of a noticeable lack of symmetry about the plate centre. Further work on the programme has been temporarily suspended until magnitudes and colour indices needed for the application of colour-magnitude corrections are available for more of the zone than the $9^h$ at present covered.

The astrographic refractor was brought back into service in 1950 April. In addition to its casual use for photographing comets, unidentified moving objects, novae and other objects of special interest notified through Copenhagen, it has been employed in systematically observing Ceres, Pallas, Juno and Vesta, with the object of improving the knowledge of the position of the equinox. The numbers of plates of these minor planets secured since April are respectively 13, 16, 19 and 11; more than half of the total of 59 have been measured and reduced. Some time has been spent in a systematic investigation of various procedures in reducing astrographic plates; methods suited to different circumstances (especially to different ways of cataloguing the reference-star positions) have been critically assessed.

At the suggestion of Professor R. O. Redman, long exposures have been made on regions containing the most intense discrete sources of galactic radio noise, the intention being to repeat the plates after the lapse of a year so as to discover whether any very faint object shown has a large proper motion. Four such plates have been secured of the fields in Coma Berenices and in Cygnus.

The 10-inch guiding telescope was used to observe occultations of several of the Pleiades in the early morning of October 28. The 3-inch Cooke lens used at the 1948 eclipse has been temporarily mounted beside the astrographic refractor in order to determine its optical distortion by means of star-field photography.

With the Yapp 36-inch reflector, 135 spectra of 96 stars have been secured, mostly for examining late-type binaries in the ultra-violet, for studying the incidence of emission in H and K, and for exploring luminosity effects in Ko sub-giants. Nine spectra of Nova Lacertae were also obtained. An exposing shutter enabling direct photography to be carried out at the Cassegrain focus has been fitted to the telescope, but bad weather in the latter part of the year has prevented its use in this way for exposures on the radio-stars in the Galaxy.

In the laboratory, the 7-inch object glass of the Cooke Reversible Transit Circle has been dismantled for measurement of its optical constants, and a complete trigonometrical ray-trace carried through to determine its aberrations. This confirmed the existence of the coma which had been found in using it. A similar trace through a proposed design for a lens to replace it shows that this should be entirely free from coma.

A total of 54 scale plates were ruled during the year for the parallax programme at the University of London Observatory, Mill Hill.

The vacuum distillation plant has been used for aluminizing various of the smaller mirrors in use at Greenwich and Herstmonceux; and much experience has been gained in " blooming " optical surfaces by coating all the lenses and graticules in the 3-inch finders attached to the astrographic refractor and the Yapp reflector.

*Time Department.*—The Bamberg broken transit was in use throughout the year at Abinger, and 222 observations were obtained on 114 nights. At Greenwich, using small transit B, 253 observations were obtained on 142 nights. Thus the total number of observations available for the determination of clock performance was 475.

The Time Service continues to utilize the quartz clocks used by the Post Office and the National Physical Laboratory, as well as those installed at the Observatory stations at Abinger and Greenwich, and the cooperation of these two organizations is of the greatest value. The new type of clock, employing a ring-crystal supported by silk threads, continues to give better results than the earlier pattern employing a GT-cut crystal. Two ring crystals have already been installed at Abinger, and were brought into immediate use. Four further crystals of the same type have been ordered. Development work on new crystal-drive circuits is making progress, and promising results have been obtained. New pulse-type dividers have been designed and constructed, and are now undergoing long-term tests: they provide signals at intervals of one second, controlled directly from the 100 kc./s. crystal-frequency, and thus replace both the conventional dividers and the phonic motors.

A service of standard frequency transmissions was started during the year by the Department of Scientific and Industrial Research, and is maintained from the Post Office Radio station at Rugby. The Abinger 2 Mc./s. transmissions have accordingly been discontinued. The Royal Observatory makes daily checks on the new transmissions.

The service of rhythmic time signals controlled from the Observatory and emitted at $10^h\,00^m$ and $18^h\,00^m$ daily from the Post Office GBR transmitter at Rugby inaugurated in 1927 December, was provided primarily for navigational purposes, being designed to permit accurate checking of chronometers by the method of coincidences. For the accurate checking of frequency equipment at frequency standardizing laboratories, signals consisting of dots spaced at intervals of a mean-time second are more convenient. The schedule of the $10^h\,00^m$ and $18^h\,00^m$ transmissions has accordingly been amended since 1950 October 1, and now includes a five-minute series of seconds dots (from $09^h\,55^m$ to $10^h\,00^m$ and $17^h\,55^m$ to $18^h\,00^m$) followed by a series of rhythmic dots, 61 to the minute (from $10^h\,01^m$ to $10^h\,06^m$ and $18^h\,0^m$ to $18^h\,06^m$). It is hoped that the new transmissions will enable users to select the form of time signal most appropriate to their needs.

The programme for the determination of the trans-Atlantic travel time of radio time signals was abandoned, owing to continued difficulty in the reception of the Rugby radio signals at the U.S. Naval Observatory at Washington. Information on the effective surface speeds of radio waves, determined by purely radio methods, has recently been published, and it is not considered profitable at present to devote further attention to investigations based on time-signal reception. It is now well established that the effective surface speed of both long- and short-wave signals is about 290,000 km./s.

*Optics Laboratory.*—Work on the Photographic Zenith Tube has continued. The console and control panel have been completed and operate satisfactorily. Construction of the mechanical components is at an advanced stage. Two modifications of design may be noted. For the rotary reversing mechanism the essential features of the previous system of cables have been retained (though the design has been altered in detail); but the cables are now operated by solenoids which move vertically along segmented rods and are impulsed at convenient intervals. The final pressure against the rotary stops is applied by one or other of the solenoids, and approach to the stops is made slow by oil damping. This system has permitted a simplification of the rotary clamping mechanism. The auxiliary frame, which surrounds the main tube of the instrument and supports various ancillary components such as the synchronous motors, has been modified so that it is now attached directly to the sole-plate of the instrument instead of to the concrete pier. This makes the whole system self-contained and greatly facilitates assembly and adjustment.

Laboratory experiments have been made to test the possibility of producing satisfactory photographic records of flashes of a millisecond duration from a continuous source of light. The results indicate that for the chronographic system of the P.Z.T., and also for that of the Horizontal Transit Instrument, it would be feasible, if desired, to replace the strobotron type of lamp by a continuous source. Preliminary experiments were made with the mercury horizon for the P.Z.T. These confirmed that flotation of the basin effects a definite improvement in insulation from mechanical vibration.

The measuring machine for the stellar plates of the P.Z.T. has received considerable attention. The errors of the existing machine have been re-examined, and some undesirable mechanical features analysed. Tests have also been made on focusing and parallax errors. Plans have been prepared for a new machine. Apart from improvements in the mechanical constraints the main innovations would be: the use of a comparator system in which the screw is replaced (as the basis of measurement) by a linear scale used in conjunction with an optical micrometer; the employment of a special optical system of superposition which makes the setting of the carriage non-critical; and the employment of auto-collimation to obtain the relevant critical knowledge of transposition-angle and, incidentally, of accuracy of mechanical constraints.

Further preliminary work on the Horizontal Transit Instrument has been in progress. Several additional pentagonal prisms of the built-up type and of various designs have been acquired; experiments are being conducted to determine their secular, thermal and postural stability.

A number of re-calibrations of the striding levels of the small reversible transit instruments which are used at Greenwich and Abinger have been made in the Laboratory. For this purpose a new apparatus has been set up in which the scale of measurements is provided by an auto-collimator and fine adjustment is given by the method described in the *Journal of Scientific Instruments*, **21**, No. 7, 1944 July. From these tests it appears that there are liable to be points of instability on the scale of the level; at these the bubble refuses to assume a position of rest, and in their neighbourhood the actual scale value may differ markedly from the mean value.

The Laboratory has examined the Occultation Machine constructed at Greenwich in 1934 for the Nautical Almanac Office with a view to possible

improvements in certain respects. The main modifications which are being applied to the machine are: a new method of setting the moon-guiding bar by optical projection; a new method of setting for declination; and a new optical system for defining the boundary of the cylindrical shadow.

*Solar Department.*—The Sun was photographed on 265 days. For 1950, there are three days unrepresented by either Herstmonceux, Cape, or Kodaikanal. Cape negatives have been received in duplicate up to 1950 June 30. Seven negatives have been received from Kodaikanal to fill the gaps in the Greenwich-Cape series for 1949.

The measurement of the combined series has been made from 1947 January 8 to 1948 June 1. Tables of the mean daily areas and mean latitudes of sunspots for each solar synodic rotation in 1945 have been published in *Monthly Notices* 1950. The Greenwich Photoheliographic Results for 1939 are in the process of reproduction.

Several plates of good definition were again secured at Herstmonceux, especially in the months August to October.

The spectrohelioscope used at Greenwich since 1929, which remained there in use after the removal of the main part of the Solar Department in 1949 May, was brought from Greenwich and re-erected in the new solar building at Herstmonceux on February 16. The second spectrohelioscope (part of the Newbegin gift) had already been installed in January. A small camera box has been fixed to the latter instrument to enable the $H\alpha$ line and adjacent spectrum to be readily photographed on 16 mm. film, alternating with visual observations in the field of the spectrohelioscope.

The Sun's disk was observed in $H\alpha$ on 136 days; on 25 of these, observation was possible only for fifteen minutes or less. 105 measures for any small line-of-sight motions were made on normal and flare patches of bright flocculi associated with sunspots, most of these measures also giving effective line-widths of $H\alpha$. 79 measures were also made on dark filaments on the disk and 11 measures on limb prominences. Line-of-sight velocities for dark filaments exceeded 100 km./sec. in two cases, the maximum value being 250 km./sec. inwards to the Sun on March 13. 58 sets of photometer measures were made collectively on normal bright flocculi and flares. 24 solar flares were observed. Only 2 flares, however, were observed in the third quarter of 1950 and none in the last quarter—an indication of the temporary lapse of chromospheric activity during the latter part of the year. The only flare observed of importance 3 was on April 12. The curve of the central intensity of $H\alpha$ throughout the life of this flare is given in *The Observatory*, **70**, 164, 1950.

In connection with the recording of solar flares by radio technique, the sudden phase-anomaly indicator receiving GBR Rugby on the frequency of 16 kc./s. (18·7 kilometres) was altered in July so as to record sudden enhancements of atmospherics on a frequency of 27 kc./s. (11·1 kilometres). The change was desirable because of the increasing number of extended periods when GBR was not transmitting on this low frequency. The changeover to S.E.A. recording is not however as satisfactory as was hoped owing to interference, and reception on other frequencies will be explored.

*Nautical Almanac Office.*—The routine work on the preparation and proof-reading of the *Nautical Almanac* and other publications of the Office has been continued. Printing difficulties and delays still make it impossible to advance

the dates of publication, and the *Nautical Almanac* for 1952 will not be published until early in 1951. No further changes have been made in the contents of the Almanac.

The arrears of the occultation programme are being rapidly overtaken. The annual discussion of observed occultations for the year 1946 has been published in the *Astronomical Journal* and that for 1947 is with the printers. The combined lists of all observations for the years 1943–1947, which will give full details of observers, instruments, observations, reductions and residuals from the adopted solutions, will be reproduced photographically as part of *Greenwich Observations*. Consideration is being given to a revision of the prediction programme, which has been continued unchanged; as a first step arrangements have been made for a complete overhaul, and some rebuilding, of the Occultation Machine, which has been in regular use during the past 15 years.

The *Abridged Nautical Almanac* for 1952 is complete and awaiting final printing. Every effort has been made to minimize the disturbance to the navigator caused by a complete change of method; user opinions are awaited with interest.

The *Star Almanac* for 1951 was published in September; it has been well received by surveyors and it should fill a definite gap in the provision of star positions.

The first machines (Hollerith) of the punched-card installation were delivered in May, but the principal machine (an IBM Calculator, Model 602A) has only just (a few days after the end of the year) been delivered. Operation has accordingly been much restricted, but a good deal of work has been done on the machines. In particular a start has been made on the systematic calculation (for about 150 transits a year for each of 256 stars) of the apparent places of stars for the P.Z.T. programme; this is the first large-scale computational work undertaken by the Office for the rest of the Observatory.

Much purely navigational work has been done during the year, including the computations for the North British Decca Chain.

The Conference on the " Fundamental Constants of Astronomy " held in Paris in March was attended by the Astronomer Royal and the Superintendent. The resolutions of that Conference, if agreed to by the International Astronomical Union, will affect the work of the Office, particularly the calculation of the lunar ephemeris. During the year consideration has also been given to the method of calculating corrections for aberration and the inclusion in the ephemerides of short-period terms of nutation.

The Office started the systematic observation of occultations in September using the Newbegin telescope; the ten observations made this year are the first night-time astronomical observations made at Herstmonceux.

### *Royal Observatory, Edinburgh*

(*Director, Professor W. M. H. Greaves, F.R.S., Astronomer Royal for Scotland*)

*Stellar spectrophotometry.*—The spectrophotometric study of early-type stars has been continued by Dr E. A. Baker and Mr R. Wilson. The work at the telescope is well advanced, and has therefore been confined to good nights and to the fainter equatorial stars involving long exposures at special times.

52 spectra were secured on 32 nights. Towards the end of the year the observing programme became so well worked out over certain hours of Right Ascension as to allow the reflector to be used for studies of star scintillations (see below).

During the work on stars of Draper type Oe5 published in 1949 (E. A. Baker, *Publications of the Royal Observatory, Edinburgh*, **1**, No. 2) the *He* I line λ6678·15 was found to be unsymmetrical. The question whether this was due to instrumental causes or to a blended line was examined in the first place by finding the instrumental profile, using a krypton tube kindly loaned for the purpose by the Research Laboratories of the General Electric Company. The photometric difficulties were reduced by using a simultaneous fogging light from a continuous source through the spectrograph slit. Some asymmetry in the instrumental profile was anticipated from double reflections in the unequal facets of the slit jaws in use up to the end of 1949 September, when they were replaced by jaws made by the Pitter Gauge and Precision Tool Co.; but the asymmetry found was much too small to account for the observed effect in the λ6678 line. In the second place the plates were re-measured to cover a number of the lines of the series $5^2G$–$n^2H^0$ of ionized helium, one line of which, at λ6683·2, is in the position of the suspected blend. It had already been concluded from the absence of any appreciable disturbance of the *Hα* profile by the line of this series given in Moore's Table at λ6570·0 that the series, which has not previously been observed, was extremely weak; it was subsequently realized, however, that this wave-length is erroneous, and that the correct figure is 6527·2. A diagram given in the publication quoted above (Fig. 1, p. 16) shows very clearly the presence of a line at this point in spectra of Oe5 stars and its absence in B3 spectra, in spite of overlying water vapour lines, and of the fact that the maximum depression is not much over one per cent of the continuum. Five lines of the series lying between *Hα* and the D lines have now been measured by Mr Wilson in 39 spectra of type Oe5 stars; the mean intensity of these lines is found to be 0·16 A. with a standard error of ±0·02 A. The consequent correction to the intensity given in Table IV of the publication quoted above for the λ6678 line may be as high as one-fifth of its amount.

The results found for the Oe5 type stars for the "interstellar" absorption near λ4430 showed a close proportionality to colour and gradient excess. The measures of this absorption band in B1 type stars, even omitting such an exceptional object as P Cygni, do not show so close a proportionality, and the factor of proportionality is markedly lower. The red star P Cygni, which has an intense and complex interstellar K line, shows comparatively little absorption near λ4430, preliminary measures giving a lower value than those of the blue star ε Persei.

*Blue Sun.*—Three spectrograms of the "Blue Sun" of September 26 were secured on Kodak P 25 emulsion by Mr R. Wilson, using the 36-inch reflector and the two-glass prism train of the spectrograph. An equal-altitude comparison with the normal Sun was carried out, the spectrum of the latter being photographed at a later date with the telescope aperture stopped down to ⅛ square inch to obtain comparable negatives. The derived extinction curve over the wave-length range 3800–6300 A. showed blueing on the long wave-length side, and reddening on the short wave-length side of a minimum situated at λ4350.

Such a minimum is produced in the extinction curve for scattering by dielectric spheres. There can be little variation in the size of the scattering particles, since

a range of diameter ratios of as little as two to one would suffice to cause the maxima and minima of the extinction curve to overlap and thus destroy the blueing effect. The Meteorological Office, Air Ministry, states that the haze originated in the smoke of forest fires burning in Alberta on September 23. Hence, during their passage to Europe, the size range of the particles must have been greatly reduced by some atmospheric filtering process.

A comparison between the observed and theoretical extinction curves leads to information relating to the size of the scattering particles. The material is now being prepared for publication.

*Stellar photometry.*—A small number of plates taken with the 10-inch camera has been measured by Mr Schneider with the Kipp star actinometer. The standard errors of measurement have been investigated and distance corrections have been derived for the lens. The main programme, however, awaits the completion of the 16/24-inch Schmidt telescope, under construction by Messrs Cox, Hargreaves and Thomson, the erection of which in the West dome of the Observatory was commenced in December.

*Solar work.*—Work has been continued with the combined spectrohelioscope and spectrograph by Dr M. A. Ellison. The Sun was observed in $H\alpha$ light on 127 days. Accurately oriented disk drawings for sunspots in white light were secured on 97 days with a 5-inch solar image.

Twenty flares were observed during the year, classified as follows: Class 1, sixteen; Class 2, four. As compared with the total of 41 flares observed in 1949, these figures represent in part the greatly reduced solar activity in 1950, especially during the second half of the year, and in part the very unfavourable observing weather experienced this year by comparison with 1949.

Line-width measures of the $H\alpha$ emission line, both in flares and in the bright *plages* near sunspots, have been continued as opportunity permitted. The greatest value of $H\alpha$ line-width was 7·5 A., recorded in the Class 2 flare of April 14.

Investigations connected with the ionospheric effects of solar flares have been continued. In particular, a detailed comparison was made between the $H\alpha$ line-width curves of development for thirteen well-observed flares in 1949 and the corresponding sudden ionospheric disturbances recorded in five independent ways. This work was described by Dr Ellison at the Solar Physics Colloquium held in Dublin on September 21 and has been published during the year as Volume 1, No. 4 of the *Publications* of the Observatory.

The long-wave receiver, installed in 1949 June for the automatic recording of sudden enhancements of atmospherics arising from the ultra-violet radiation of flares, has been in continuous operation throughout the year. Recording on a frequency of 22 kc./s., it has provided most valuable evidence, both positive and negative, for the occurrence of major flares in daylight hours. There was a sudden and very striking drop in the frequency of the sudden ionospheric disturbances during the months of June to December, parallel to the fall in solar flare activity referred to above. Reports of solar flares and of sudden enhancements of atmospherics have been supplied, as formerly, to a number of establishments and individuals requiring them.

Miss M. Conway, a research student, completed in May her studies of the profile of the $H\alpha$ line in prominences. An account of this work was submitted as a thesis for the degree of Doctor of Philosophy in the University of Edinburgh.

The degree has since been conferred and Miss Conway has left to take up an appointment on the staff of Dunsink Observatory.

*Stellar scintillation.*—Some experiments on stellar scintillation have been carried out by Dr Ellison and Mr Wilson. The first of these employed an objective prism attached to a 5-inch aperture aerial camera: the spectrum of Sirius, when viewed through an eye-lens vibrating at right angles to the plane of dispersion, showed the presence of rapid scintillations in monochromatic light (*Nature*, **165**, 664, 1950 and *The Observatory*, **70**, 60, 1950). Photographs of this phenomenon have since been published by F. Zwicky (*P.A.S.P.*, **62**, 150, 1950).

To investigate the matter further, early in the autumn a multiplier photocell (type R.C.A., 931–A) was installed, together with suitable guiding arrangements, so that it would receive the light from a star as it reached the Cassegrain focus of the 36-inch reflector. The D.C. output of the cell, caused by its response to the light from a 1st magnitude star, is of the order of 10 microamperes when measured with a moving-coil galvanometer. In fact, however, it is found that this current is subject to variations with a frequency of the order of a hundred per second arising from the atmospheric scintillations of the stellar beam. These variations are recorded as voltage changes on the screen of a cathode ray tube and are photographed by means of a moving film running through at speeds of up to 1 foot per second. An account of the preliminary results, which are of much interest, will shortly be prepared for publication. The experiments are being continued with the object of studying scintillation on a quantitative basis. In this work we have had the cooperation of Dr A. C. B. Lovell, of the Jodrell Bank Experimental Station of the University of Manchester, and of Dr C. B. Childs, of the Department of Natural Philosophy, Edinburgh University.

*Publications.*—The following have been distributed in addition to those mentioned in previous reports :—

Astrographic Catalogue, Perth Section, Dec. $-40°$, R.A. $6^h\,00^m$ to $23^h\,50^m$ (continuation of *Perth Astrographic Catalogue*, Vol. XXXIII). This volume, containing the measures made at Edinburgh of the Perth plates, was printed in Paris and published under the auspices of the International Astronomical Union. It has been distributed by this Observatory. (The second volume, containing the results for Dec. $-39°$, has been printed and will be distributed during 1951.)

*Publications*, Vol. I, No. 4—Ionospheric Effects of Solar Flares—by M. A. Ellison.

*Communication*—Characteristic Properties of Solar Flares—by M. A. Ellison. Reprinted from *M.N.*, **109**, 3, 1949.

*Seismology.*—The Milne-Shaw seismograph (East–West component) has been in operation throughout the year. We are indebted to Lt.-Col. E. Tillotson for reading the records and distributing the results.

*Visitors.*—Our visitors during 1950 included members of the Science Masters' Association during their meeting in Edinburgh in January; the Committee on Radio-Astronomy of the Royal Astronomical Society in February; and members of the British Astronomical Association (Scottish branch) in May. Among visitors from abroad we were pleased to welcome Professor F. Becker (Bonn); A. C. Banerji (Allahabad); W. Becker (Hamburg-Bergedorf); L. Randić (Zagreb); and C. E. Hesthal (Ohio).

*Staff.*—Mr H. Schneider, Scientific Officer, resigned his appointment at the end of November to take up a studentship at the University of Edinburgh. Mr D. G. Thorn, Scientific Assistant, resigned at the end of the year.

### *Royal Observatory, Cape of Good Hope*

(*Director, Dr R. H. Stoy, H.M. Astronomer*)

*Reversible Transit Circle.*—The modernization of this instrument, to which reference was made in last year's report, went on steadily throughout 1950. The twelve cameras for recording the circle readings were received from the workshops of the Trigonometrical Survey in February and were mounted on the piers together with the subsidiary gear that automatically controls the exposures. The second half of the year was spent experimenting with the drive of the R.A. micrometer, in constructing a new chronograph and in commencing the construction of a projection measuring machine for the 35 mm. films on which the circle readings are recorded.

All the observations that have been made with this instrument in past years are completely reduced and are ready for publication.

*Photographic zone observations.*—The typescript for the zone $-35°$ to $-40°$ (12,115 stars) is complete except for a short introduction and has been sent to the Hydrographer for direct photolithographical reproduction. About one-quarter of the typescript for the zone $-30°$ to $-35°$ has also been prepared. The manuscript copy for press for the zone $-52°$ to $-56°$ (9000 stars) was started and completed up to $14^h$ of R.A. The reduction of the measures to the final positions was completed for the zone $-60°$ to $-64°$ (7000 stars) and proper motions computed up to $8^h$ of R.A. For the zone $-64°$ to $-68°$ (5000 stars), standard coordinates of the stars to be measured were computed from $7^h$ to $24^h$ of R.A. The measurement of this zone was started and completed up to $2^h$ of R.A.

*Parallax programme.*—Since the start of this programme in 1926, the parallaxes of nearly 1700 stars have been determined. The programme is almost worked out. Of the 300 stars that remained on the working list at the beginning of 1950 all but 55 have now got sufficient observations and have been removed from the list.

During 1950, 696 normal parallax plates were obtained and 108 plates for the determination of proper motion. 2211 plates were measured for parallax and 221 rejected, leaving 8299 plates still to be measured. The number of rejected plates is considerably greater than usual since it includes plates of a number of stars for which a parallax determination was originally contemplated but which after one or two plates had been obtained were considered to be unsuitable for further observation.

Parallaxes were derived for 57 stars. Of these 57, 14 were fresh determinations for stars of which the parallax had been determined at the Cape.

*Stellar photometry.*—(i) Zone Magnitudes. Steady progress was made with the measurement of the photographic and photovisual magnitudes of the 23,600 stars in the zones between $-52°$ and $-64°$. The measures and reductions to the S system of magnitudes were completed as far as $20^h\ 48^m$.

Early in 1950 Professor Redman sent provisional magnitudes on the North Polar System for the stars in the Kapteyn Selected Areas at $+15°$ which had

previously been observed from South Africa. From a discussion of these data it appears that the only correction required by the S system to bring it into coincidence with the International System is a change of zero point of $0^m{\cdot}07$. Thus within the limits of ambiguity with which the two systems are at present defined

$$IPg = SPg - 0{\cdot}07,$$
$$IPv = SPv,$$

the tie for zero point and colour being at about $8^m{\cdot}5$.

Owing to the unsatisfactory nature of the present International System there seems little likelihood that these relations will be significantly altered for some time to come. It has therefore been decided to adopt these relations as final and to use them when preparing the zone magnitudes for publication. This is the more justifiable in that any further systematic corrections to the S system are likely to prove smaller than the accidental errors of the zone magnitudes.

During 1950 the magnitudes of the 12,115 stars in the $-35°$ to $-40°$ zone were re-examined and small residual colour, scale and zero-point corrections applied. These magnitudes were included in the catalogue of positions and proper motions of these stars that was sent to the printers. A similar examination of the magnitudes of the 13,000 stars in the $-30°$ to $-35°$ zone was started.

(ii) Bright Star Magnitudes. Considerable progress was made with both the "Bright Star Programmes" during 1950 and they are now nearing completion. These programmes aim at determining accurate photographic magnitudes and photoelectric colours for all the 850 "non-variable" stars south of $+6°$ whose H.R. magnitude is 5·0 or brighter. For the first of these programmes 6823 observations, each with two exposures, were made with the Fabry photometer attached to the Astrographic Telescope. For the second programme 3926 observations were made with the photoelectric photometer attached to the 7-inch telescope.

When the programme for determining the photographic magnitudes of the bright stars was started in 1945, the inherent accuracy of the Fabry photometer was not fully realized and the original aim was to attain a standard error of $\pm 0^m{\cdot}03$. The present aim is an internal standard error of $\pm 0^m{\cdot}01$ and as the stars are scattered all over the sky extra observations had to be made to ensure the constancy of the zero point. These observations, which compared as many stars as possible directly with suitable stars in the E regions, are now all but complete. The original programme of observing the stars in series when at a constant altitude of either $60°$ or $50°$ has been continued. The $60°$ portion is virtually complete and the few stars in this list which need further observation have been transferred to the $50°$ list.

(iii) Parallax Star Magnitudes. This programme, which was begun by Dr Jackson in 1948, aims at providing photographic and photovisual magnitudes for all the stars whose parallaxes have been, or are being, determined at the Cape. Though this programme was not complete at the time of Dr Jackson's retirement, considerable progress had been made and preliminary results had been incorporated in Volume XVI of the *Cape Annals*, which gives the details of some 600 of the Cape parallax determinations. It is hoped to complete Dr Jackson's original programme and to extend it to include all stars in the Southern Hemisphere for which a sensible parallax has been determined.

In connection with this programme, 960 observations, each in two colours, were made during 1950 with the Fabry photometers attached to the Victoria Refractors.

(iv) Standard Magnitudes in the E Regions. Considerable effort is still being devoted to determining standard magnitudes in the nine E regions at $-45°$ declination. The work on stars brighter than $10^m$ is nearing completion and more attention is being given to the stars with magnitudes between 10 and 14. The following paragraphs give an account of the present state of this work.

Fabry Observations. The observation of stars between $7^m{\cdot}0$ and $11^m{\cdot}0$ Pg and between $6^m{\cdot}5$ and $9^m{\cdot}5$ Pv with the Fabry photometers attached to the Victoria Refractors was continued as opportunity offered. In 1950, 579 observations were made in both colours and 387 observations in the photographic alone.

Observations made with the schraffierkassette attached to the Radcliffe 74-inch Reflector. The object of these observations, which were begun by Mr Cousins during his visit to Pretoria in 1949, is to extend the E region sequences to stars fainter than those that can be conveniently observed at the Cape. 50 more plates for this programme were obtained by Dr Stoy during a visit to Pretoria in 1950 May and the plates needed to complete the original programme were obtained later in the year by Dr David S. Evans of the Radcliffe Observatory. This series of plates should provide sufficient material to give Pv magnitudes down to about $14^m{\cdot}5$ over an area of $45' \times 45'$ surrounding each E region. The corresponding Pg magnitudes are being obtained from plates taken several years ago with the Victoria Telescope. During 1950, 39 s-k plates and 15 Victoria plates were measured and reduced.

Durchmusterung of Faint Stars. When the measurement of the fainter stars on the s-k and Victoria plates was commenced, the need was felt for a comprehensive list of stars in each of the E regions. To meet this need and also to provide a rational basis for the choice of suitable stars to act as standards, a start has been made with a Durchmusterung of all stars in an area of $1° \times 1°$ surrounding each E region. The ultimate intention is to provide approximate coordinates with Pg and Pv magnitudes for all the stars in this area brighter than $15^m{\cdot}0$.

(v) The Kirkwood Expedition. At the invitation of H.M. Astronomer, Professor John B. Irwin and Mr Arthur N. Cox of the University of Indiana visited the Cape Observatory in 1950 September and installed on the Victoria Telescope the photoelectric photometer that they had previously used in America and at the Radcliffe Observatory. Professor Irwin had to return to America soon after the photometer was installed but Mr Cox stayed at the Cape as a guest until the end of 1951 January. During this period he completed the following programmes:

(1) The observation in two colours of the Harvard No. V Standard Sequence in the Larger Magellanic Cloud and the No. 1 Standard Sequence in the Small Magellanic Cloud and the comparison of these sequences with standard magnitudes in the E regions.

(2) The observation of the colours and magnitudes of numerous early-type stars in the two Magellanic Clouds.

(3) The transfer of the zero point and colour equation of the standard magnitudes in three E regions to three C regions at $+15°$ declination.

(4) Observations of magnitude and colour of stars in three Galactic Clusters with the intention of deriving the magnitude-colour arrays. (20 selected stars

in N.G.C. 6381, 108 stars in N.G.C. 2287 and 50 stars in N.G.C. 2516.) All the observations were made twice and most of them three or four times. The zero point for the magnitudes was obtained by repeated transfers from the E regions.

Though Mr Cox did most of the observing for these programmes he was assisted for part of the time by various members of the staff so that they could obtain some experience of photoelectric work. Towards the end of the year, when the Kirkwood programmes were well in hand, the photometer was used by the observatory staff to observe stars in the E regions. Between September and December 31, 1909 observations each in two colours were made with the Kirkwood photometer.

*Photoheliograph.*—The Sun was photographed on 345 days, two photographs being taken on each day except two. 27 photographs were taken with double exposures to determine the orientation of the reference wires and visual observations for the same purpose were made weekly. All the plates have been sent to Herstmonceux for measurement at the Royal Greenwich Observatory together with similar plates obtained there.

*Occultations.*—84 observations of 43 phenomena were made with various telescopes at the observatory. Of these, 61 were disappearances at the dark limb, 6 were disappearances at the bright limb and 17 reappearances at the dark limb. The data from these observations were sent quarterly to the Nautical Almanac Office together with those from 22 observations made at Pretoria by Mr S. C. Venter.

The occultations of Antares in May and June were of particular interest since Antares is one of the few stars occulted by the Moon that can be expected to show a measurable diameter. Preparations were made both at the Radcliffe and Cape Observatories to observe these occultations photoelectrically in an attempt to measure the duration of the occultation and thus deduce the apparent diameter of the star. Successful observations indicating a diameter of 0·04 seconds of arc were made at the Cape in May and at Pretoria in June.

At the Cape the Victoria Telescope was used and to it was attached a photoelectric photometer specially designed by Professor Guelke of the Electrical Engineering Department of the University of Cape Town and built in the observatory workshop. The oscillograph and recording camera were loaned by the Physics Department of the University of Cape Town.

*Variable stars.*—During 1950, Mr R. P. de Kock made 5454 observations of 165 variable stars of long period using the Six-Inch Telescope. Mr de Kock observed each star as nearly as possible at five-day intervals. The observations were forwarded monthly to the headquarters of the American Association of Variable Star Observers at the Harvard Observatory.

*Publication of observations.*—The printing of the *Second Cape Catalogue for 1925·0* and of *Cape Annals*, Vol. XIV, Part 4 (Observations of the Sun, Mercury and Venus 1925–36) was completed during 1950. The following typescripts ready for direct reproduction by photolithography are at the printers: The *Third Cape Catalogue for 1925·0*, the *First Cape Catalogue for 1925·0* and *Cape Annals*, Vols. XV and XVI (Details of parallax determinations).

*Staff.*—Dr John Jackson, C.B.E., F.R.S., retired from the office of H.M. Astronomer on July 31. Mr J. H. Peirce, the senior Assistant, retired on November 30.

### *Armagh Observatory*

(*Director, Dr E. M. Lindsay*)

*Equipment.*—The most important event of the year has been the erection of the Armagh–Dunsink–Harvard Baker–Schmidt telescope in South Africa. Long-exposure photographs which have been received from Professor Bok testify to the high efficiency of the instrument. The firm of Perkin Elmer Corporation, of Glenbrook, Conn., have finished the optical figuring of a 33-inch objective prism for the ADH telescope. Funds for this have so far been provided by Harvard University and Queen's University, Belfast. After considerable delay the Armagh Schmidt has now been erected and final adjustments and tests are in progress. The synchronous motors for our special meteor cameras ordered eighteen months ago have only just arrived and tests are commencing. During the summer a new dome was fitted on the 10-inch refractor building.

*Publications.*—Nos. 3–5 of the *Contributions* have been distributed. *Contribution* No. 6 on "Collision Probabilities with the Planets and the Distribution of Interplanetary Matter" by E. J. Öpik, and *Contribution* No. 7 on "Transport of Heat and Matter by Convection in Stars" by E. J. Öpik, have been accepted by the Royal Irish Academy and the Council of the R.A.S. respectively. *Armagh Observatory Leaflets* Nos. 1–6 have been distributed.

*Miscellaneous.*—Lectures in the Department of Astronomy, Queen's University, Belfast, were given throughout the academic year. Meteorological work was continued as usual. Visitors to the Observatory numbered 1879.

Mlle Tilka Prince, a graduate of Geneva University, arrived in September and will remain for the rest of the academic year for theoretical work on Stellar Interiors.

### *The Observatories, Cambridge University*

(*Director, Professor R. O. Redman, F.R.S.*)

*Staff.*—The Observatories have lost the services of Dr T. W. Wormell, Observer in Meteorological Physics since 1926, and of Mr E. T. Pierce, Junior Observer since 1945, following the transfer of the work in Meteorological Physics to the Cavendish Laboratory, on 1950 September 30. Dr Wormell's post lapses, while Mr Pierce has been succeeded by Mr D. W. Dewhirst, of Christ's College. Mr R. H. Cullum has been appointed laboratory assistant, and Miss R. M. Ives as secretary-librarian.

*Re-equipment and reconstruction.*—The remodelling of the mural circle room, reported last year, has been finished. The new workshop has progressed as far as its roof. Dislocation in the engineering industry, caused by metal shortages and the impending rearmament programme, threatens serious delay to completion of the new 16/24-inch Schmidt telescope and the 36-inch reflector. The optical parts for these two instruments are likely to be finished before their mountings, contrary to the usual experience. Plans have been completed for rebuilding the McClean solar installation.

*Solar research.*—Measurement of the 1949 plates for determining the general magnetic field of the Sun has been completed, and the results have been communicated to the Society. The polar field in the reversing layer was

zero, with an internal probable error about 0·4 gauss. Photographs taken in 1950, following essentially the same method with some improvements in detail, are now being measured.

The McClean spectrograph has also been used without an interferometer, to try to measure sunspot magnetic fields, using infra-red lines at about λλ 8400 and 10,300 A. respectively, whose Zeeman separation is unusually large. The work has been interrupted owing to difficulty in the supply of suitable infra-red photographic material.

Observations have been continued to try to detect in the solar spectrum a displaced K line, arising from matter supposed thrown off the Sun during a chromospheric flare, but definite results are not available, as no really suitable flare occurred in good observing weather during the year. A photoelectric apparatus has been constructed, allowing such measures to be made in integrated sunlight from a cloudy sky. The chief difficulty arises from the wide range of light intensity thus received, but the method promises to form a useful supplement to direct observations on the solar disk.

The Lyot filter has been tried on both the Thorrowgood 8-inch and Newall 24-inch refractors. It gives good definition on the solar image, but several improvements are considered necessary. It is therefore being reconstructed so as to transmit a narrower range of wave-length, to allow use of a "line shifter", to permit the disk to be screened off when prominences only are observed, and to eliminate troublesome oil leaks.

The spectrohelioscope is being rebuilt, and a spectrograph added to allow photography of flare spectra down to 3000 A. The Sun was observed in *Hα* with the old spectrohelioscope on 23 days, data on 3 flares seen during this period being sent to the *Quarterly Bulletin of Solar Activity*. Calcium K spectroheliograms have been received from Kodaikanal for dates down to 1950 September 30.

The Rowland grating mounting has been dismantled and in its place an infra-red spectrometer is approaching completion, incorporating a lead sulphide cell and a 14,400 lines per inch grating. Interferometric work planned for this spectrometer requires knowledge, not at present available, of the infra-red properties of thin metallic films. An apparatus for the preparation of such films by evaporation has been completed; it can deal with optical parts up to 10 inches diameter.

Construction has commenced of instruments for observing the total eclipse of the Sun of 1952 February 25 in the Sudan. Four problems are being attacked: accurate photometry of the corona in polarized light, infra-red intensity measurements in the corona, measurement of the Balmer discontinuity and of line widths in the chromospheric spectrum.

*Stellar photometry*.—The combined photographic and photoelectric programme on pg and pv magnitudes in the range 7–10·5 pv. in the +15° Selected Areas is approaching completion. On the photographic side about four-fifths of all plates have been measured and reduced, while nine preferred areas, viz. SA 68, 70, 73, 76, 78, 81, 84, 86, 89 have been finished completely. These nine areas have also been observed with the pulse-counting photoelectric photometer, in two colours, 715 polar comparisons having been made on 442 stars. To allow a final accurate reduction to the NPS system and to

complete the whole work, observations now required are limited to a comparatively small number at the Pole only.

The pulse-counting photometer on the 15-inch Huggins refractor has been used on 117 nights, although not all of these yielded useful measures, principally on account of sky irregularities. The photometer was rebuilt early in the year, to improve the resolving time of the counters, so as to make the instrumental response more nearly linear. On good moonless nights measures can be made to $11^m$ without refrigeration of the photomultiplier. A similar photometer has been constructed for use on the 3-foot reflector and is nearly finished.

Photoelectric observations in two colours have been made of a few eclipsing variables. A number of measures were made on ζ Aurigae during its recent eclipse ; re-emergence took place about half a day later than predicted.

A programme of infra-red photometry on a small number of bright stars, using a lead sulphide cell with the 3-foot reflector, has been finished. Accuracy has been satisfactory, the chief restriction being lack of sensitivity. A considerable area in the vicinity of the strong radio source in Cygnus has been scanned with this apparatus, without discovery of any bright infra-red object. Observations of ε Aurigae have failed to detect the infra-red companion postulated by Kuiper and his collaborators.

*Optics.*—Further progress has been made with the theory of aberration-balancing in Schmidt cameras. An approximate solution has been obtained of the problem of minimizing in mean square, over a given angular field, the aberrations (including chromatism) of a Schmidt camera by combined modification of plate profile and focal surface.

Diffraction theory has been used to investigate the properties of the phase-contrast test for optical surfaces in the convenient modification where a slit replaces a pinhole as light source, and a phase-retarding strip is used instead of a disk. It appears that the modified form can safely be used in working surfaces to an accuracy of about $\frac{1}{20}$ fringe.

A programme of work on the diffraction theory of optical instruments has been started, the ultimate purpose being to investigate the space-penetrating power of telescopes, especially Schmidt telescopes. Formulae relating to the three-dimensional distribution in diffraction images near focus have been obtained which supplement Lommel's and Struve's classical results, and which are now being applied to the diffraction theory of refracting telescopes.

Work has continued on the construction of a 12/15-inch two-plate Schmidt-Cassegrain camera and also on the fifth-order aberration theory of such optical systems. A general analytic theory of monocentric Schmidt-Cassegrain systems has been successfully developed.

*Other investigations.*—To assist interpretation of band intensity measurements in the solar spectrum, the total absorptions in the $7{\cdot}8\,\mu$ and $8{\cdot}6\,\mu$ bands of nitrous oxide diluted by dry air have been measured in the laboratory over a wide range of conditions, as a function of nitrous oxide mass and total pressure.

A small grating spectrograph with a Schmidt camera working at $f/1{\cdot}5$ has been given preliminary tests on the 3-foot reflector, spectra being photographed down to $9^m$.

Occultations of ten Pleiades were observed on 1950 October 28, and the results communicated to H.M. Nautical Almanac Office.

## *Cavendish Laboratory*

### (*Director, Sir Lawrence Bragg*)

The Radio Astronomy section of the Cavendish Laboratory has been concerned with three main problems: (*a*) the study of the solar corona, (*b*) the location and investigation of "radio stars" (the discrete sources of radio waves in the galaxy), and (*c*) the investigation of the "twinkling" of radio stars.

*Solar observations.* (*a*) *Routine observations.*—Regular observations of the Sun on wave-lengths of 1·7 m. and 3·7 m. have been maintained since 1946 December (**1**). The sensitivity of the apparatus used in this series of observations has been sufficient to enable the solar radiation to be observed at all times, and not only during the passage of sunspots. Similar observations have also been maintained on wave-lengths of 6·7 m. and 60 cm. since 1949 February, but these latter observations have had to be discontinued temporarily owing to shortage of staff.

In addition to the measurement of intensity, daily measurements of polarization are made, and any special occurrences are noted. The results have been communicated to the *Quarterly Bulletin of Solar Activity* and latterly to *Solar Radio Noise.*

(*b*) *Interferometer measurements of localized sources on the Sun.*—Interferometers of large resolving power are available on wave-lengths of 1·4 m. and 3·7 m. for the measurement of the diameter and position of the intense sources of radio waves associated with sunspots (**1, 7**). Regular observations are made during times of enhanced radiation. The absolute accuracy with which the position of a source of enhanced radiation can be determined is limited by uncertainties in the alignment of the aerial system, and is about 2 minutes of arc; the accuracy of determining the apparent position is very much better, and observations with this apparatus have enabled the rapid movement of the effective centre of the source to be studied as well as allowing the longer period movements to be followed.

(*c*) *Interferometer measurements of the undisturbed Sun.*—Previous attempts to measure the distribution of radio "brightness" across the solar disk in the absence of sunspots were based on observations of the variation of intensity during an eclipse. This method has not proved satisfactory at wave-lengths longer than 10–25 cm., largely owing to the disturbing effects of small sunspots at the longer wave-lengths. An alternative method has therefore been developed which does not depend on an eclipse and which can therefore be carried out on selected days of small sunspot activity. In this method, observations of the Sun are made with an interferometer of variable spacing and from the amplitudes observed at a large number of different spacings the distribution across the solar disk can be determined (**2, 7**).

The results obtained at a wave-length of 60 cm. showed (**2**) that the radio "brightness" is constant from the centre of the disk to a radius of 0·7 $R_\odot$ (where $R_\odot$ is the photospheric radius) and then falls continuously to $\frac{1}{10}$ of the central value at a radius of 1·5 $R_\odot$. There is therefore no evidence for the "limb-brightening" predicted by some of the theories.

A similar experiment has also been carried out on a wave-length of 3·7 m., which shows a continuous decrease of "brightness" from the centre of the disk (**3**).

(*d*) *Theoretical investigations.*—Theoretical work on the emission of radio waves both from the undisturbed Sun and from sunspots has been carried

out (**4**). In addition a detailed analysis has been made of the two major types of mechanism which have been put forward to account for sunspot radiation (**5**) :—

1. Those which are based on some special mechanism for maintaining the coherent oscillation of a number of electrons.

2. Mechanisms based on an " equilibrium " radiation process and the maintenance of particles of high energy in the solar corona near sunspots.

It has been shown that there are very great difficulties associated with the former type of mechanism under the conditions of the solar corona.

*Galactic observations.*—Observations of " radio stars " were started in 1948 May (**6**), and are now carried out on wave-lengths of 1·4 m., 3·7 m., 6·7 m. and 8 m.; in each case a spaced-aerial interferometer has been used (**7**). The greater part of this programme has been concerned with a survey of the radio stars of the Northern Hemisphere, using a wave-length of 3·7 m. In this survey 50 radio stars have been located ; the absolute positional accuracy for the more intense sources is about 5 minutes of arc, but for the weaker sources it is more than 1°. The relative accuracy for the major sources is very much better, and a time of transit may be determined with an accuracy of about 0·25 seconds.

Attempts to identify the more intense radio stars with a number of different types of stellar body have been unsuccessful ; the two most intense radio stars, for which the best positional accuracies are possible, are not related to any visual body brighter than 11th magnitude. Four of the weaker radio stars are, however, significantly related to four of the five major extra-galactic nebulae (M 31, M 33, M 101 and M 51).

These results have been discussed in detail in a recent paper to *Monthly Notices* (**8**), where it was concluded that the majority of the radio stars so far observed must lie within the Galaxy. An analysis of their angular distribution has shown no significant concentration towards the galactic plane, and it is therefore concluded that they are likely to be situated at distances small compared with the dimensions of the Galaxy.

Attempts to measure the annual parallax of the two most intense radio stars have been unsuccessful ; the minimum distance corresponding to the accuracy of the present observations is about $2 \times 10^{16}$ cm. (0·01 parsec).

Owing to the difficulty of accounting for more than about 1 per cent of the observed " background " radiation from the Galaxy by mechanisms based on the emission from the interstellar gas, the possibility that it is simply the integrated radiation from unresolved radio stars has been investigated. An analysis of the 25 most intense radio stars in the northern hemisphere (**7**) has shown that on this hypothesis the population density of radio stars within the Galaxy must be comparable with that of visual stars.

*Refraction effects in the terrestrial atmosphere.*—At times the intensity of the radiation from radio stars exhibits rapid fluctuations, and a detailed investigation of the phenomenon is important, not only because of its disturbing effect on observations in Radio Astronomy, but also from the point of view of determining the origin of the fluctuations. A continuous series of observations of the four most intense radio stars has therefore been made on a number of wave-lengths over the past two years. In addition to observing the rapid variations of the intensity, measurements with aerial systems of large resolving power have shown that there are simultaneous variations in the

apparent position of the radio star ; under normally disturbed conditions, the apparent position may vary irregularly by as much as 3 minutes of arc at a wave-length of 6·7 m.

By simultaneous observations of the intensity at two separated receiving sites, and by simultaneous measurements of the intensity and apparent position of a radio star, it has been possible to show that the refraction processes occur in the terrestrial atmosphere and not in the interstellar region. It has further been possible to show that the irregularities (which appear to be located in Region F of the ionosphere) have lateral dimensions of the order of 5 km. and an additional ionization corresponding to a variation of the thickness of Region F of only 0·1 per cent.

In addition to the expected increase of the effect at large zenith angles, there is a marked diurnal variation which can only be interpreted as an actual variation of the irregularities. This variation exhibits a marked maximum at $01^h\ 00^m$ local time, and it therefore does not seem possible to account for the phenomenon in terms of emissions from the Sun.

One possible explanation which was put forward in a recent paper to *Monthly Notices* (**9**) is based on the interception by the Earth of interstellar matter moving under the solar gravitational field. If this hypothesis is correct, further and more refined observations might provide important evidence for theories of the accretion of interstellar matter by the Sun.

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*University Observatory, Glasgow*

(*Director, Professor W. M. Smart*)

The analysis by Dr T. R. Tannahill of the 33,000 proper motions of the *General Catalogue* on the two-streams hypothesis has neared completion. The analysis proceeded, first, according to each of the spectral types F, G and K; second, according to each of four galactic zones, Zone I being associated with the galactic equator; the final analysis referred to all the stars concerned. The results of general interest, shown below in tabular form, relate to the coordinates of the vertex of star-streaming and to the coordinates of the solar apex.

| | | Spectral Type | | | Zone | | | | All |
|---|---|---|---|---|---|---|---|---|---|
| | | F | G | K | I | II | III | IV | Stars |
| Vertex | Long. | 349° | 342° | 342° | 349° | 341° | 341° | 345° | 343°·1 |
| | Lat. | −1° | −2° | −3° | −3° | 0 | −4° | +2° | −1°·7 |
| Solar Apex | R.A. | 266° | 272° | 278° | 270° | 276° | 274° | 280° | 273° |
| | Dec. | +28° | +37° | +40° | +32° | +35° | +35° | +35° | +35° |

Dr P. A. Sweet has completed two papers :—

(i) " The effect of turbulence on a magnetic field " (*M.N.* **110,** 69, 1950), in which it is shown theoretically that turbulence reduces the effective conductivity of a gas, in some cases to a small fraction of its normal value; (ii) " The importance of rotation in stellar evolution " (*M.N.*, **110,** 548, 1950). In this paper Eddington's work on meridian-plane circulation in the Sun is put on a mathematical basis and extended to stars in general; it is shown that the critical speed of rotation of stars, as affecting evolution, lies within the actual observed range.

Dr Sweet has also been attempting to show that the magnetic field in sunspots prevents the normal convection in the hydrogen convection layer, even although the lines of force are vertical; this would account for the darkness of a spot and for the apparent absence of granulation. He has also been extending his work on turbulence to the case of anisotropy.

### *Imperial College Observatory, South Kensington, London*

*(Director, Assistant-Professor R. W. B. Pearse)*

The second edition of the compilation of data on molecular spectra, completed last year by Dr Pearse and Dr Gaydon, has now been published. Dr M. Afaf completed his work on the spectrum of *ZrO* and returned to Pakistan. Dr M. W. Feast was awarded a Canadian Postdoctorate Fellowship at the National Research Council, Ottawa, and has continued his investigation of molecular spectra there. He has observed new band systems for *NO* and $NH^+$. The study of the absorption of metal vapours in atmospheres of hydrogen and helium in the ultra-violet and vacuum ultra-violet regions of the spectrum has been continued by Mr W. R. S. Garton. The metals so far used in these experiments include *Al, Fe, Ga, Ge, In* and *Sn*. Experimental and theoretical studies of the transition probabilities and intensity distribution for a number of band systems have been made by Miss M. Pillow and Dr G. Stephenson.

The Director attended the meeting of the Joint Commission for Spectroscopy at Cambridge, 1950 September, and gave a lecture entitled " Fundamental Research in Molecular Spectra ".

### *University of London Observatory, Mill Hill*

*(Assistant Director, Dr E. M. Burbidge)*

*The Radcliffe Telescope.*—The 24-inch photographic refractor was used on 108 nights, during which observations made before and after midnight were 69 and 58 respectively. The total number of plates taken was 1007, and almost all of these were for the determination of parallax. Four positions of the asteroid 51 Nemausa were obtained and transmitted to Copenhagen Observatory. Following a suggestion by Professor R. O. Redman, 8 plates were exposed on positions, provided by the group working on radio astronomy at Cambridge, of the two strong sources of radio noise in Cygnus and Cassiopeia. A preliminary comparison of pairs of plates taken of the Cygnus source with an average interval of about four months revealed no detectable displacement of

any star brighter than magnitude 16 within about 40′ of the estimated position of the source. The limiting magnitude shown by the plates is between 17th and 18th, but not all of the faintest stars shown have been examined yet.

*Other instruments.*—The Wilson 24-inch reflecting telescope and 4-prism spectrograph were used on only a few nights, for spectra of Be stars.

Little further progress has been made with the optical work on the mirror meridian instrument owing to difficulty experienced by the Optical Works, Ltd., Ealing, in obtaining the necessary skilled labour.

The other instruments were used mainly for teaching purposes and for visitors. Astronomy courses have been taken by two postgraduate and six undergraduate students during the year.

*Publications.*—The second list of parallax determinations, to be published in *Monthly Notices*, is in the press, the first list having appeared in *M.N.*, **109**, 478, 1949.

Most of the reduction of the spectra obtained at Haute Provence, referred to in the last annual report, has been completed, and a paper entitled "Hydrogen and Helium Line Intensities in some Be stars", by E. M. and G. R. Burbidge, to be published in the *Astrophysical Journal*, is in the press.

A note on "The Spectrum of HD 217050", by E. M. and G. R. Burbidge, has been submitted to the *Astrophysical Journal*.

*Staff.*—Mr C. C. L. Gregory resigned from the Committee of Management of the Observatory in June, and from the Directorship on September 30. He is for the present continuing to work at the Observatory as Research Associate.

Mr G. R. Burbidge continued to give voluntary assistance with the parallax observations, and joined the regular staff as Assistant Lecturer on October 1.

Mr S. K. Wang began work in August as a plate measurer, and is studying astrophysics.

Mr F. Steel, after completing his M.Sc. thesis on the determination of stellar parallax, was employed as a plate measurer during July and August before being called up for military service.

M. G. de Vaucouleurs, of the Institute of Astrophysics, Paris, commenced some part-time voluntary work at the beginning of the year, and has completed the measurement of parallax plates for two stars.

*Visitors.*—The number of visitors was 326, of whom a large number were from schools, colleges and local societies for young people.

## *Jodrell Bank Experimental Station, University of Manchester*
## (*Director, Dr A. C. B. Lovell*)

This report has been prepared by invitation of the Council of the Royal Astronomical Society and, at their request, deals mainly with work which has not yet been published. As a background to the present account the recent surveys of Hey (1), Ryle (2) and Lovell (3) may be consulted.

*Radio-frequency emission from the Galaxy.*—The 220 ft. aperture paraboloid has been used in a survey of the galactic radio emissions since 1947. It is not possible to incline the beam of this instrument more than $\pm 14°$ from the zenith and hence the investigation is confined to the zenithal strip between declinations $+39°$ and $+67°$. The measurements are in progress by

Hanbury Brown and Hazard over a range of approximately 1·9 m. to 8 m., with the following specific applications:—

(*a*) Determination of the frequency spectrum of the unresolved background radiation, for comparison with the corresponding spectrum of the radio stars.

(*b*) Comparison of the contours on the different frequencies.

(*c*) Determination of the number/intensity distribution of the radio stars in the 1·9 m. experiment where the beam width is $\pm\frac{3}{8}°$ and the sensitivity limit is about $5 \times 10^{-26}$ watts/cm.$^2$/c.p.s.

(*d*) Detailed study of the individual contours with the $\pm\frac{3}{8}°$ beam.

With the results from (*a*), (*b*) and (*c*) it is hoped to establish the extent of any contribution from the interstellar gas and the population of the radio stars. Much work remains to be done in these experiments, but the preliminary conclusion is that the contribution from the interstellar gas must be very small and that the main part of the galactic emission arises from a large number of radio stars. This is in line with the conclusions drawn by Ryle (**2**) and by Bolton (**4**) from their interferometric measurements on the 50 most intense radio stars.

(*d*) is to be regarded as a preliminary exercise in the possibility of investigating galactic structure with the narrow beam. The region around Cygnus appears to be of great interest. In addition to the intense radio star, there exists a very prominent diffuse maximum (**30**). This agrees well with the conclusion of Bolton and Westfold (**5**) who interpret their survey measurements as indicating a spiral structure of the Galaxy.

*Radio-frequency emission from the extragalactic nebulae.*—During the summer of 1950 the beam of the large paraboloid on 1·9 m. was inclined to survey the region of the Andromeda nebula (M 31). Hanbury Brown and Hazard (**6**) have given a short account of the successful measurement of the radio emission from the nebula and the full results of the investigation have now been compiled (**7**). These indicate that M 31 is closely similar to the local galaxy in the overall intensity of its radio emission. All the prominent nebulae in the zenithal strip referred to above are now being surveyed in order that the intensity of the radio emission can be compared with their visual characteristics.

*Scintillation of the radio stars.*—The experiments made by Little and Lovell (**8**) in conjunction with Smith (**9**) demonstrated that the fluctuations in intensity of the radiation from the radio stars were introduced in a local ionospheric region. This work has been continued by Little and Maxwell (**10**), using spaced receivers over short base lines with continuous following of the sources. The results show that the occurrence of the fluctuations when the radio stars are at high elevation is closely associated with the occurrence of discontinuities in the F region of the ionosphere (Spread F). Near lower culmination of the Cygnus and Cassiopeia sources fluctuations are always marked. In these cases the sight line passes through the auroral zone and hence other ionospheric disturbances may also be the cause of the fluctuations under these conditions. An analysis of the correlation coefficient at different receiver spacings indicates that the ionospheric disturbances are of the order of 4 km. in size. An explanation of the phenomena in terms of diffraction of the radiation as it penetrates an inhomogeneous ionospheric region has been given by Little (**11**) who also considers the normal stellar scintillation to arise from a similar diffraction process in the troposphere.

*Solar radio-frequency emission.*—Continuous recordings of the radio emission from the Sun are made on a wave-length of 3·7 m., mainly for monitoring purposes in connection with other programmes. Spaced receiver observations have been made in conjunction with Ryle at Cambridge in an attempt to verify that all the fluctuations in sunspot emission originate in the source. Although the programme is not yet concluded, it is evident that only a small proportion, if any, of the fluctuations can have a local ionospheric origin. Details of the unusual emission from a spot crossing the meridian on 1950 June 14 have been given by Maxwell (**12**).

*The velocity distribution of sporadic meteors.*—The first part of the programme on the velocity distribution of the sporadic meteors, using the radio echo diffraction technique, was completed in the spring of 1950 and a short note on the results has been published (**13**). The full details of the work have now been compiled (**14**). The measured distribution of the velocities of the meteors lying in a great circle plane through the apex of the Earth's way shows agreement with the theoretical distribution calculated on the assumption that the meteors are moving in random directions at the parabolic velocity limit. Earlier criticisms that the apparatus possessed a cut-off above 72 km./sec. have been met by using a longer wave-length for the measurements and also by repeating the work for the meteors lying in a great circle plane through the antapex of the Earth's way. The final conclusion is that a negligible percentage of the meteors down to 5th magnitude can be moving with hyperbolic velocities. The work has since been extended to fainter meteors with similar results.

*The daytime meteor streams.*—Since their discovery in 1947 (**15**) the summer daytime meteor streams have been investigated in more detail. An indication of their short-period nature was obtained in 1948 (**16, 17**), and during 1950 combined work by Aspinall and Hawkins (**18**), Davies and Greenhow (**19**) and Miss Almond (**20**) enabled four of the orbits to be computed. These all have periods of only a few years. One appears to be coincident with the orbit of Encke's comet which is now presumed to give rise to the autumn Taurid shower and the June daytime $\beta$-Taurid shower. Another is associated with the return of a minor stream visible at night in the autumn. The Arietid shower, which is the dominant stream of the sequence, may be related to the well-known $\delta$-Aquarid shower. Apart from the association with Encke's Comet, these orbits seem more likely to be related to some minor planets than comets. Further observations will be necessary to assess the recurrent nature of the other streams previously delineated.

*The continuous meteor survey.*—The continuous survey of meteoric activity has now continued without interruption since the spring of 1949. A full description of the apparatus which enables radiant coordinates to be delineated to $\pm 1°$ (R.A.) and $\pm 1\frac{1}{2}°$ (Dec.) has been published (**21**). In addition to recording systematically the major showers (including the daytime streams) valuable data are being acquired about the distribution and variation of the sporadic activity throughout the year.

*Bečvář's meteor stream.*—The orbit of this stream, discovered by Bečvář in 1945, was computed from the observations made in 1949 (**22**). The orbit agrees well with that of Comet Tuttle 1790. The observations made in 1950 December confirm this result.

*Meteor heights.*—A very large number of meteor heights have now been measured, for both shower and sporadic meteors, using the method described by Clegg and Davidson (**23**). The chief analysis is being carried out in conjunction with the problem of the duration of the radio echo (for summary of difficulties, see Lovell (**24**)). In addition a search is being made for any diurnal or seasonal influences on the heights of occurrence.

*Electron density in meteor trails.*—An experiment is in progress by Clegg and Closs in which the intensity of the scattered wave from a meteor trail is measured simultaneously on two polarizations, one along the trail and the other at right angles. An appreciable polarization effect would indicate that the trails are over-dense for the radio frequency in use and hence the scattering formula developed by Lovell and Clegg (**25**) would not apply in such cases. So far the results indicate that such a polarization does, in fact, exist for a certain proportion of the shower meteors (**31**). The full development of this technique should lead to a much more accurate estimate of the relation between electron density and meteor magnitude than has hitherto been possible.

*Behaviour of the meteor trail after formation.*—The violent fluctuations in amplitude of the long-duration radio echoes from meteor trails have now been studied in detail by Greenhow (**26**), using two wave-lengths simultaneously. The effect is interpreted as due to a break-up of the trail under the influence of turbulent winds which produces several favourable reflecting centres. The relative movement of these then gives rise to an interference pattern moving across the observing station. A general account of the influence of winds on the meteor trail ionization has been given by Ellyett (**27**).

*Radio echo studies of the Aurora Borealis.*—The continuous operation of the meteor survey equipment described above has proved of great use in studies of the aurora borealis. Some of the earlier work in which electron densities have been measured has already been described (**28, 29**). With the survey equipment it has been possible to identify particular aurora forms with certain types of radio echo. A recent analysis by Hawkins of 18 months' records indicates that in the diurnal distribution there is a pronounced maximum of activity centred on $18^{h}\ 00^{m}$, probably arising from homogeneous arcs. There is also a marked 27-day recurrence period.

*Lunar radio echoes.*—Early in 1950 successful attempts were made by Moran and Gatenby to obtain radio echoes from the Moon, using a long-pulse (20 mill second) narrow band-width apparatus on 4 m. wave-length. Because of the deep fading of the lunar echo the signal strength proved insufficient to carry through any programme of work and the apparatus is being redesigned.

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## *University Observatory, Oxford*
## (*Director, Professor H. H. Plaskett*)

***Solar work.***—Work has been continued during the year on the determination of solar wave-lengths, on motion in sunspots and on granulation. A definitive set of spectra for the interferometric determination of wave-lengths in the Sun and the vacuum iron arc was obtained by Dr Adam in the $\lambda$ 5100 region during June, July and August. These spectra have all been measured and the reduction is well advanced. Mr Kinman, using Evershed's positive on negative method of measurement, has determined the sight-line velocity at 75 places in the large symmetrical spot of 1949 September. Other spectra of this spot await measurement; in addition it is hoped to secure spectra of another suitable spot as soon as one presents itself. Additional spectra for the determination of the motions of solar granules were obtained in April and May, but the measurement of these and earlier spectra has not yet been commenced.

Two new pieces of research were begun during 1950. In spite of cloudy weather during the period of normally good seeing in September and October, Miss A. B. Hart obtained 12 pairs of equatorial spectra for the determination of solar rotation; in addition photometrically calibrated spectra were made for finding scattered sky light and its effect on the observed sight-line velocities. Half of these spectra have been measured by the Evershed method. The Rev. P. J. Treanor, using the interferometric method developed by himself, obtained in July photometrically calibrated spectra with a practical resolving power in excess of 500,000 of some of the lines used by Allen in his determination of non-isotropic turbulence in the Sun. It is hoped to find accurate profiles of these faint lines.

*Comets.*—Dr Merton has continued his photographic observations of comets. He has adjusted and tested a Linfoot achromatic Schmidt-Cassegrain camera of some 8 inches aperture and 14 inches focal length for use in cometary photography.

### *University Observatory, St. Andrews*
### (*Director, Professor E. Finlay-Freundlich*)

*Staff.*—Mr T. B. Šlebarski was appointed Lecturer from 1950 October 1. Dr J. Cisař worked as Observer with the 20-inch Schmidt-Cassegrain telescope at the Mills Observatory, Dundee. R. Waland and E. Finlay-Freundlich paid a two months' visit to various observatories in U.S.A. to discuss problems concerning the telescope project in St. Andrews.

*Scientific research.*—The 20-inch Schmidt-Cassegrain pilot model was completed and attached to the mounting for the 19-inch reflector at the Mills Observatory in Dundee. Extensive optical tests are going on with which Dr Cisař was entrusted during the absence of R. Waland and E. Finlay-Freundlich. Grinding of the 38-inch disk, the main mirror of the full-scale Schmidt-Cassegrain telescope, has begun.

Optical research work was continued by W. L. Wilcock and A. H. Jarrett. An evaporation plant was installed early in the year and suitable modifications for producing dielectric coatings of controlled thickness carried out. The degree of control over the coatings was ascertained by measuring independently the thickness of the deposit by an interference method, the error from the desired $\lambda/4$ thickness being approximately 4 per cent.

High reflection multilayer films for use in Fabry-Perot interferometers have been prepared, and photometric measurements of their transmission have confirmed their superiority over silver films, e.g. a reflecting coefficient of 93 per cent at 5461 A. can be attained with 9 quarter wave-length layers (i.e. 5 layers of zinc sulphide with 4 cryolite layers interposed alternately between them), the absorption being less than 3 per cent. It is hoped to use such coatings shortly in solar studies; meanwhile further work on enhanced metal films is in progress. An investigation has commenced into the application of the Fabry-Perot interferometer to stellar spectra, and a promising variant of the normal etalon is being explored.

### *Norman Lockyer Observatory*
### *of the University College of the South West*
### (*Director, Mr D. L. Edwards*)

Work on relative gradients has been continued and a paper on the results obtained for $\gamma$ Cassiopeiae submitted to the Society. Such work, however, has been greatly hampered by bad weather and by extensive repairs to the domes which have made the telescopes unusable for some months. Subsidiary researches connected with this work have been made on atmospheric extinction and the nature of the absorption band at 4430 A.

Whilst the telescopes have been out of commission, work on the twilight sky has been extended, and additional evidence of a suspected influence of solar flares on the polarization of the zenith skylight at 5893 A. has been obtained. In connection with this work it is planned to supplement the photoelectric twilight observations by spectrophotometry of zenith sky light during the day and, in collaboration with the Physics Department at Exeter, to observe spectra of ozone—air mixtures under different conditions of excitation.

### *Dunsink Observatory*

*(Director, Professor H. A. Brück)*

*Staff.*—Dr Mary T. Conway after working at the Royal Observatory, Edinburgh, has joined the staff as Assistant Astronomer. Mr A. N. Argue, B.Sc., of Trinity College, Dublin, has been awarded a scholarship at the Observatory.

*Re-equipment.*—The construction of the 7-metre concave grating solar spectrograph has been completed during the past year, apart from the installation of an automatic temperature control which has to wait for the arrival of some parts.

The newly constructed aluminizing plant has been put into operation, and mirrors of up to 16 inches diameter have been coated successfully.

A new photoelectric photometer has been constructed and attached to the 15-inch Roberts reflector, and various photoelectric arrangements have been set up for the recording of stellar scintillation and lunar occultations.

*Stellar photometry.*—Weather conditions have been unusually poor during the past year for making any extended series of observations possible. However, sufficient records of stellar scintillation have been obtained to allow the study of the relation between amplitude and frequency of scintillation and factors such as stellar altitude, colour and meteorological conditions. Preliminary reports of the results have been sent to *The Observatory*, while a more detailed investigation is in progress.

*Visitors.*—The past year has been notable for the great number of astronomers who have visited the Observatory. Among individual visitors were Professor Fr. Becker of Bonn, and Canon Lemaître, of Louvain. On September 22 about 150 Fellows of the Royal Astronomical Society, members of the Irish Astronomical Society, and distinguished guests such as Mr de Valéra, accepted an invitation to the Observatory on the occasion of the Dublin meeting of the Royal Astronomical Society. An account of the various scientific and social events which took place in connection with this meeting, will be found in *The Observatory*, 1950 October.

### *Dominion Observatory, Ottawa*

*(Director, Dr C. S. Beals)*

*Stellar physics.*—An analysis of the spectra of the P Cygni stars as a class was completed and published during the year. This study, which was based on observational material originally collected at the Dominion Astrophysical Observatory at Victoria, includes suggestions as to the nature and origin of P Cygni emission as well as a discussion of the place occupied in the Harvard sequence by all early-type emission-line stars.

Theoretical studies of envelopes in early-type stars, in particular those showing evidence of ejection of material from their surfaces, have yielded contours in good agreement with observed spectra. The role played by scattering in determining a P Cygni or related profile has been shown to be important and in certain instances it has been shown that the profile may be a consequence of scattering alone. Certain spectral features hitherto unexplained have been shown to be a normal consequence of the scattering mechanism.

For solar studies in conjunction with the horizontal telescope a combined grating spectrograph and spectrometer of 20-foot focal length is under

construction. Preliminary plans have been made for the observation of solar activity with a polarizing interference filter.

The cooperative programme of meteor observation, commenced in 1947 by the Dominion Observatory and the National Research Council, was continued. Observations were carried out during the Lyrid, Perseid and Geminid meteor showers as well as on a number of nights when no particular annual shower was active. Approximately 3000 visual meteors were plotted during these observations and 200 meteor photographs were secured. The National Research Council operated radio equipment at four stations. Statistical results are being compiled in a card catalogue of all meteors observed by both visual and radar methods from the same station. Preliminary results for the mean heights of various types of radar echoes associated with the annual meteor showers were published, and a study was made of the relation between echo duration and visual meteor luminosity.

The work on the analysis of meteor spectra was continued. A short note was prepared on the spectrum of a meteor trail photographed in 1948. A bright detonating fireball that appeared in the Montreal-Ottawa district at 7.35 p.m. E.S.T. on 1950 November 2, was investigated by personal interviews with observers.

*Positional astronomy.*—Meridian circle observations on the Backlund–Hough stars, Sun, Venus and Mercury, taken 1923–35, have been computed and results are being typed ready for printing. They will be published in 1951. The observations taken from 1935 to 1950 are being computed.

Some changes have been made in the illumination for photographic recording of the declination circle division marks. The motors for advancing the films had to be changed to overcome failures in cold weather. A machine for measuring the films has been constructed in the Observatory machine shop and is proving satisfactory.

Observations are being made on a list of stars that are to be used with the photographic zenith tube at Greenwich; Richmond, U.S.A.; and Ottawa.

As in the past, nightly observations of time have been made with a broken type transit. Foreign time signals have been monitored regularly and time has been broadcast continuously over station CHU on 3330 kc./s., 7335 kc./s. and 14,670 kc./s. and once daily on the C.B.C. network.

*Seismology.*—Operation of the permanent network of Canadian seismograph stations has continued. Plans for the improvement of the Halifax station, announced last year, are well advanced, most of the new instruments having been already received. The new seismic observatory at Resolute Bay, N.W.T. (N. 74° 41′, W. 94° 54′) began operation on August 18. The station employs two long-period Sprengnether horizontal seismographs and a short-period vertical of the same make. Radio messages, giving the readings of principal phases, are received almost daily and are being used in world-wide epicentral determinations.

Research continues into the seismicity of western Canada and into the large earthquake of 1949 August 21. A paper on the mechanics of its generation is in the press. Professor Jean Coulomb of the Institute de Physique du Globe, of the University of Paris, who was attached to the Observatory during the summer months, prepared a paper on the surface waves of this same shock.

The study of the crustal structure in the vicinity of Kirkland Lake is nearing completion, the final analysis of a large body of records being now under way.

*Terrestrial magnetism.*—The magnetic survey of Canada was energetically pursued. Ninety-seven field stations were occupied in the area bounded by latitudes N. 46°·7 and N. 74°·7, and longitudes W. 53°·1 and W. 118°·8. These comprise 42 repeat and 55 new stations.

Two isomagnetic maps delineating vertical and total force for that part of Canada lying to the south of latitude N. 75° were constructed. Over 1000 magnetic declination values were computed and supplied for the revision of marine charts, and topographical and air navigation map sheets.

The magnetic observatories at Agincourt, Ontario; Meanook, Alberta; and Baker Lake and Resolute Bay, Northwest Territories, continued to operate in a normal manner.

Further progress was made in the construction of an airborne universal magnetometer of the electrical type and its ancillary apparatus.

*Gravity.*—Some 2500 gravimeter observations were taken across Canada and were distributed among the 10 provinces more or less in proportion to their relative areas, with the exception of British Columbia, in which only four observations were made. Two hundred and eighty-nine observations employing air transport were taken in an area of 100,000 square miles in northern Manitoba, north-eastern Saskatchewan and the adjoining area north of 60° latitude in the Northwest Territories. Seven hundred and fifty observations were taken over the Stirling ore deposit in Cape Breton, Nova Scotia. One hundred and fifty observations were taken over an area of 1000 square miles on the ice cap (latitude 70°) on Baffin Island, with a view to the determination of its probable thickness.

Seven thousand eight hundred and four observations of gravity have now been made in Canada by the Observatory since the initial gravimetric observations were begun in 1944. Most of these were observed along highways by motor transport. Some 100 stations have been observed by rail transport along railways which cannot be reached conveniently by automobile. One thousand and sixty-two observations have been made by air transport, covering the northern portions of Ontario, Manitoba, Saskatchewan, the north-eastern corner of Alberta, and the adjoining areas in the Northwest Territories to the north of the three western provinces.

Publications dealing with the results of 500 stations observed in the Maritime Provinces in 1944 and the results of observations over one of the ore bodies have been prepared and published. Preparation of the remaining data is proceeding, and the work is expected to be ready for publication early in 1951.

### *David Dunlap Observatory, University of Toronto*

### (*Acting Director, Professor J. F. Heard*)

*Radial velocities.*—During the year observation and measurements have been continued on the general programme in Yale Zone 25° to 30°. The velocities of 223 stars of this programme have been reported to Mount Wilson Observatory for inclusion in the forthcoming Mount Wilson general catalogue. Professor Heard has also reported the velocities of 21 faint Be stars. Some observations have also been made on a programme of 369 stars between

photographic magnitudes 7·5 and 8·0 in the areas 6°×6° centred on the Kapteyn areas north of the equator.

Miss R. J. Northcott has continued orbit determinations of spectroscopic binaries.

*Photometric.*—Dr Helen Sawyer Hogg has completed a study of variables in Messier 9 and nearly completed the period and light curves for 51 variables in NGC 6934. Mr R. L. Baglow has continued to study six eclipsing binary systems with the photomultiplier photometer on the 19-inch telescope, to which has now been added a D.C. amplifier.

*Miscellaneous.*—Professor R. E. Williamson has made theoretical investigations concerning the source of radio noise in the Galaxy. In connection with the United States Navy–Cornell University radio astronomy project, he has been engaged in setting up a model of the chromosphere and corona of the Sun to interpret observations of solar radio noise, and has assisted with the design of observing programmes for the radio interferometer at Cornell. Mr J. B. Oke published a theoretical Russell–Hertzsprung diagram of red dwarf stars. Mr Ian Halliday published a study of the spectral variations of the star HD 218393. Mr W. R. Hossack has designed and has been constructing an oscilloscopic measuring machine for stellar spectrograms. Professor Heard has designed a set of Time Difference Star Tables for Air Navigation which have been computed by the Computation Centre at the University of Toronto.

## *Union Observatory, Johannesburg*

### (*Director, Dr W. H. van den Bos, Union Astronomer*)

The 26½-inch refractor has been out of commission during a considerable part of the year, while the electrical installation was replaced. It has been used on 41 nights for interferometer and on 11 nights for micrometer observations of double stars.

Plates taken with the Franklin–Adams telescope:

| | |
|---|---|
| Minor planets | 356 |
| Comets | 40 |
| Miscellaneous | 50 |
| Total | 446 plates. |

The minor planet 1950 KA, which showed unusually rapid motion, was discovered by Mr Johnson.

With the 9-inch refractor, 73 occultations were observed.

Counts of sunspots were made on 331 days.

During the year 955 visitors were admitted on 35 nights.

A considerable amount of additional equipment for the time service was received or made in our own workshops.

*Circulars* No. 108, 109 and 110 were printed and distributed.

Professor Oosterhoff from Leiden worked at the Observatory from the end of April to the end of August and Dr Walraven arrived during November to take over from Dr Wesselink as Leiden Observer. Astronomers Bok and Mrs Bok, Irwin, Cox, King, Stoy, Henize and Hirst visited the Observatory.

### *Radcliffe Observatory, Pretoria*

*(Director, Dr A. D. Thackeray, Radcliffe Observer)*

*Equipment.*—Work with the 74-inch reflector throughout the year has continued to be confined to the Newtonian focus. In addition to direct photography and small-scale spectroscopy, photoelectric equipment belonging to (*a*) the University of Indiana, and (*b*) the S. African Council for Scientific and Industrial Research has been used. The blink microscope belonging to the Cape Observatory has been used on loan for work on variable stars.

The Cassegrain mirror was received from Messrs Grubb–Parsons in July. The Cassegrain spectrograph by C. F. Casella & Co. arrived in the Union at the end of the year. The optical parts by Adam Hilger were received before the war. It will therefore be possible to instal this apparatus early in 1951 and, it is hoped, to begin the long-awaited programme on radial velocities of southern stars.

Progress has been made with the preparation of a 24-inch experimental aluminizing tank. The 74-inch mirror has been silvered twice during the year.

An improved R.A. setting clutch has been installed, thereby eliminating an intermittent source of trouble in the main drive for the 74-inch telescope.

*Observations: planetary nebulae.*—A survey of southern planetary nebulae 8″ of arc or larger in diameter has been completed and the results communicated to the Society.

In the course of a survey of the region of Eta Carinae a nebulous envelope around the variable AG Carinae (P Cygni type in the Harvard classification) has been discovered. Two other nebulous envelopes around P Cygni stars have also been discovered. These three stars should probably be regarded as low-excitation planetaries analogous to Campbell's hydrogen envelope star. Further observations of the red outer shell of Eta Carinae have been made.

*Diffuse nebulae.*—Two fine examples of bright-rim nebulae in the southern Milky Way have been discovered, one in the outskirts of the Eta Carinae nebula, the other near the Oe star HD 150136. Another field of nebulosity, which includes the two variables LW Cent and BH Cent, shows complex interaction between stars and nebulosity and also some dark patches with very sharp but highly irregular outlines. Many fields of nebulosity in the Large Magellanic Cloud have been surveyed.

*Elliptical nebulae.*—Isophotes of six bright southern elliptical nebulae have been obtained by photographic photometry. In general, Hubble's distribution of intensity is confirmed satisfactorily, but NGC 1553 shows an interesting intermediate plateau of small variation. A peculiar result of this work is the suggestion of a steady change in the direction of the major axes as one proceeds outwards from the centres of some nebulae.

*Variable stars.*—A preliminary note on the variables (over 200) which have so far been discovered in the Sculptor system has appeared in *The Observatory*. 35 more plates of the system have been obtained during 1950, including some comparisons with Selected Area 68.

13 plates of the Fornax system have been taken, but poor conditions have rendered many of them unsuitable for a search for variables.

Variables with periods apparently greater than 1 day have been discovered in and near the globular cluster NGC 1866 in the Large Magellanic Cloud on the basis of 61 plates taken 1948–1950.

A special study on blue and red plates of the highly reddened globular cluster NGC 6553 has revealed over 20 variables, all with periods either less than 1 day or over 100 days. Possibly not more than 5 belong to the cluster. No significant difference in the velocity of blue and red light can be detected from this material despite interstellar absorption of some four magnitudes suggested by the reddening of the cluster and by the faintness of the variables.

A few faint variables have been found in the elongated globular cluster NGC 121 near 47 Tucanae. The faintness of the variables places the object at a distance at least equal to that of the Small Magellanic Cloud and it should probably be regarded as intergalactic like NGC 2419.

102 plates have been taken of the four globular clusters NGC 4372, 4590, 6266, 6362 by Dr P. Th. Oosterhoff for studies of the variable stars at the Leiden Observatory.

Further visual observations of VV Puppis have been made.

*Standard magnitudes.*—Further photographic and photovisual plates of the Harvard E regions have been taken with schraffierkassette by Dr R. H. Stoy and by Dr David S. Evans for the extension of the Cape work on standard magnitudes.

*Newtonian spectroscopy* of globular clusters in the Galaxy and in the Large Magellanic Cloud has continued. Spectra of a few P Cygni objects in the Cloud have been obtained.

*Photoelectric photometry.*—Dr John B. Irwin and Arthur N. Cox, of the University of Indiana, have used the telescope for 30 nights for the following work:

(*a*) Four-colour photometry of southern globular clusters (integrated light) including a few in the Large Magellanic Cloud.

(*b*) Photoelectric sequences in E regions. These were connected with sequences in C regions in four colours.

(*c*) Four-colour photometry of southern c-stars.

(*d*) A four-hour run on Proxima Centauri in two colours on 1950 July 16. No significant variation in light was detected in this run.

(*e*) Polarization measures of globular clusters and a few supergiants.

*Diameter of Antares.*—With the kind cooperation of the S. African Council for Scientific and Industrial Research the occultation of Antares on 1950 June 27/28 was observed photoelectrically. While the total duration of the occultation was consistent with previous concepts of the star's angular diameter, the details of the asymmetrical curve of disappearance (steep maximum slope followed by a slow final disappearance) cannot be simply explained away. An ellipsoidal shape of Antares is suggested. Unfortunately, the only other suitable occultation of Antares on May 3/4 (reappearance at dark limb) was spoilt by clouds.

The fast-moving minor planet 1950 KA, discovered at the Union Observatory, Johannesburg, was picked up on a series of plates on May 25/26 and observed visually to be without coma.

In all, the telescope was used on 219 nights during the year. Conditions were generally poorer than average.

*Staff and visitors.*—Dr H. Knox Shaw, Radcliffe Observer since 1924, left the Observatory on retiring leave in April. He was succeeded by Dr A. D. Thackeray on October 1. Dr A. J. Wesselink was appointed Chief Assistant in December. Mr H. C. Davies, of the Cape Observatory, served as temporary mechanic for four months from October 1. For the greater part of the year the Observatory has had a resident staff of only two.

Dr John B. Irwin and Arthur N. Cox, of the University of Indiana, spent June and part of July and September at the Observatory. Dr P. Th. Oosterhoff of the Leiden Observatory and Dr R. H. Stoy, now H.M. Astronomer at the Cape Observatory, both worked at the Observatory during May. In addition it has been a pleasure to receive visits during the year from Dr Bart J. Bok, Mrs Priscilla F. Bok and Dr Ivan King, all of the Harvard Observatory.

## *Nizamiah Observatory, Hyderabad*

### (*Director, Dr Akbar Ali*)

*Astrographic Equatorial.*—35 plates were taken mostly in ecliptic regions, with the Astro Camera attached to the Astrographic Equatorial. Measures of 14,260 stars in the remaining 19 common regions of *Hyderabad Astrographic Catalogues* and Potsdam's *Himmelskarte* were compared during the year for deriving relatively large proper motions. This programme is now completed and it is proposed to publish the results shortly. Distances and position angles of 384 double stars in Zone $+37°$ have been determined and the reduction of double stars in Zone $+38°$ is in progress.

Preliminary investigations in connection with the Recommendation 3 of the Carte-du-Ciel Commission of the International Astronomical Union (1948) are nearing completion. These were undertaken to determine whether a new calculation of plate constants in the Hyderabad Zones will be justified by the precision of the star measures.

*Grubb Equatorial.*—The total number of occultations of stars by the Moon observed during the year was 36, all of which have been reduced and the results are, as usual, being communicated for publication in the *Monthly Notices.* The programme of the measurement of double stars has been continued as before.

*Spectrohelioscope.*—The routine observations of the Sun on 97 days were carried out. 18 shifts towards violet and 6 shifts towards red were observed with the line shifter.

*Publications.*—The following papers were sent for publication during the year :—

1. "Occultations of stars by the Moon observed at the Nizamiah Observatory during the year 1949." (*M.N.*, **110,** 260.)
2. "A note on the Double Star ADS 14266." (*A.J.*, **55,** 208.)

*Instruments.*—The 8-inch photovisual object glass of the Astrographic telescope was sent to Messrs Cox Hargreaves & Thomson Ltd., England, in the month of April 1950, for necessary polishing and refiguring. Great difficulties were experienced with regard to the entry of this lens into England free of Customs duty. In this connection and in other matters, I must record my grateful thanks to Mr F. J. Hargreaves who gave me his unstinted help.

*Miscellaneous.*—The meteorological and seismological work of the observatory has been continued as usual. From 1950 April 1, the meteorological work is being carried out on behalf of the Government of India on an agency basis.

It is regretfully stated that Rao Sahib T. P. Bhaskara Shastri, former Director of the observatory, died on 1950 June 26.

## *Solar Physics Observatory, Kodaikanal*
### (*Director, Dr A. K. Das*)

*General.*—A noteworthy feature of the activities of this observatory during 1950 was that a number of constructional works pertaining to development projects were taken up and appreciable progress was made in the execution of these works. The construction of a dome for housing a moderate-sized stellar telescope (20-inch Grubb reflector) and of buildings for an Ionospheric Laboratory were nearly completed; the installation of the telescope was begun, and the assembly and testing of a Multi-frequency Automatic Ionosphere Recorder Type C.R.P.L. Model C-3, received from the U.S.A., was taken up. Extensions to the library, the machine shop and the spectroheliograph buildings for providing much-needed additional accommodation were also in progress.

*International cooperation.*—Exchange of spectroheliograms and photoheliograms with foreign observatories was continued as in previous years. 264 calcium flocculus spectroheliograms obtained at Kodaikanal during the period 1949 October to 1950 September were sent to the Solar Physics Observatory, Cambridge, and 7 photoheliograms for certain specified days in 1947 and 1948 were supplied to the Royal Greenwich Observatory. 36 *H*-alpha flocculus photographs and 42 K3 disk spectroheliograms relating to the second half of 1949 were obtained from Meudon Observatory, France; the Mt. Wilson Observatory, U.S.A. also sent 55 *H*-alpha flocculus and 60 K-prominence plates for the same half year. Quarterly statements of solar flares observed at Kodaikanal were sent to Dr L. d'Azambuja of Meudon Observatory and Mr H. W. Newton of the Royal Greenwich Observatory.

Daily broadcasts of URSIGRAMMES through the All-India Met. Broadcasting Centre, New Delhi and the practice of issuing warnings of ionospheric and geomagnetic disturbances, whenever expected, were continued.

*Weather conditions.*—Weather conditions during the year were unfavourable for solar observations as far as the total number of days of observation was concerned; observations were possible on a maximum of 286 days only during the year. But the average definition of the Sun's image estimated on a scale in which 1 is the worst and 5 the best was slightly better, being 2·95 as compared with 2·9 of the previous year. There were also 50 days on which the definition was 4 or more and 54 days on which the definition was 2 or less.

*Routine observations.*—The normal observational programmes of work with the photoheliograph, the prominence spectroscope, the spectrohelioscope and the spectroheliographs were carried out uninterrupted. Direct photographs of the Sun on a scale of 8 inches to the Sun's diameter were obtained on 281 days as against 316 in 1949. Spectroheliograms of the disk in the *H*-alpha and the K lines were obtained on 286 and 266 days respectively and prominence photographs in the K line on 257 days. The observations of sky and seeing conditions during the day and the night were continued. The results of these observations show that conditions favourable for coronagraph work occur mostly during the winter months and that only the first two or three hours after sunrise are favourable for such observations. They also indicate that there is a good percentage of nights during which conditions are favourable for stellar observations.

*Sunspot activity.*—Sunspot activity during the year has shown considerable decrease as compared with the last year. The following table gives the number of new sunspot groups observed during the different months of the year, their distribution in the two hemispheres and the mean daily numbers :—

| | | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of new groups | North | 17 | 11 | 19 | 9 | 14 | 16 | 5 | 8 | 7 | 10 | 5 | 4 | 125 |
| | South | 8 | 8 | 13 | 13 | 10 | 6 | 3 | 9 | 5 | 7 | 3 | 3 | 88 |
| | Total | 25 | 19 | 32 | 22 | 24 | 22 | 8 | 17 | 12 | 17 | 8 | 7 | 213 |
| Mean daily No. | | 6·6 | 5·5 | 6·7 | 5·5 | 5·8 | 4·4 | 3·6 | 4·9 | 3·6 | 3·6 | 3·3 | 2·8 | 4·8 |

The total number of new sunspots and the mean daily number both show decreases, of 41 per cent and 34 per cent respectively, as compared with the previous year. There were three spot-free days out of the total number of days of observation. The approximate mean latitude of the spot groups for the whole year shows a very slight decrease—last year's value was 13°—the decrease being in the southern hemisphere.

*Geomagnetic observations.*—Continuous photographic recording of the horizontal and the vertical components of the Earth's magnetic force and of declination was made as in the previous years. Absolute observations of dip were made on five days in the week and those of declination and horizontal force once a week.

Two severe and twenty moderate magnetic storms were recorded during the year. The storm commencing at $05^h\,42^m$ U.T. on 1950 March 19 was the severest recorded at Kodaikanal during the year. The storm was of a sudden commencement type with an initial impulse of $58\gamma$ in $H$ and the HF trace extended very much below the base line. The range of HF during the storm was $554\gamma$.

*Research work and publications.*—A direct recording photoelectric spectrophotometer for solar line-contour work was constructed and preliminary trials were conducted to test its sensitivity and stability for the purpose in question. A similar photoelectric sky photometer (non-recording) was also constructed for the study of the variations in the intensity and the polarization of sky light in various spectral regions.

In addition to the research programmes begun in previous years, the following problems were taken up, viz. a determination of absolute solar wave-lengths in order to test how far they are consistent with the General Theory of Relativity, a study of the centre-to-limb variation of the intensity of the continuous spectrum of the Sun in different wave-length regions with a view to ascertaining how far the observed curve of absorption agrees with that of the negative hydrogen ion and the measurement of temperature in spots and other features of the solar disk, using a Moll thermocouple and a thermo-relay. The following notes were either published or sent for publication during the year :—

1. Observations of haze, clouds and growth of convection over the plains from the Kodaikanal observatory (*Indian Journal of Meteorology and Geophysics*).

2. Solar and Geomagnetic phenomena during the first, second and third quarters of 1950 (*Indian Journal of Meteorology and Geophysics*).

3. Recording photoelectric photometer (*Indian Journal of Meteorology and Geophysics*).

During the year the Government of India granted two Research Scholarships in Astronomy tenable for three years at this observatory.

### *Commonwealth Observatory, Mount Stromlo*

*(Director, Professor R. v. d. R. Woolley, Commonwealth Astronomer)*

*Solar work.*—The daily routine of sunspot sketching has been maintained, observations being made on 280 days despite the fact that the year 1950 was the wettest and cloudiest on record for many years. Registration of 200 Mc./s. solar radiation was continued and compared with spectrohelioscope and ionospheric results. Magnetic polarities of sunspots were observed.

*Time service.*—Transit observations have been made on 191 nights. An American type time signal has been commenced. It, as well as the former rhythmic type signals, is broadcast regularly from the R.A.N. Wireless Station at Belconnen. The clock corrections have been found to vary annually with amplitude of $\pm 0{\cdot}06$ seconds, apparently owing to variations in the rate of rotation of the Earth.

*Astrophysical observations.*—The light curve of HD 44701 has been determined by photoelectric observations with the Oddie refractor. The same equipment was used to obtain light curves for $\sigma$ Scorpii in blue and yellow regions. The initial programme of the photoelectric measures in the band 4500–4600 A. was completed and results for 66 stars communicated to the Society. The programme of coarse grating magnitudes has been extended by introducing a plate holder driven relative to the Reynolds telescope. This enables exposures on spectra to be repeated and hence the work can be extended to fainter stars. Tenth magnitude stars have been obtained with exposures of 15 minutes. The Harvard F1, F2 and F3 regions at declination $-75°$ have been observed and also stars in the Hyades. Reclassification of objective prism spectrograms taken with the Oddie refractor has been completed. A 3-prism slit spectrograph has been completed and with the Reynolds reflector has been used for preliminary measures of radial velocity. A nebular spectrograph has been used to obtain 45 slit spectra of various regions as well as 50 objective prism spectrograms to search for areas of emission in $H\alpha$. Work has been commenced on the comparison of radiation from calibrated standard lamps with that from the brighter stars to obtain an absolute basis for magnitude scales.

*New instruments and equipment.*—The contractors for the 74-inch telescope, Sir Howard Grubb, Parsons & Co., Ltd. have reported that the polar axis-declination axis-mirror cell assembly is complete and that a 76-inch disk has been cast for the mirror by Messrs Pilkingtons.

There has been some progress with the reconstruction of the 48-inch Melbourne telescope. It is proposed that this telescope should be primarily a Schmidt type. A 50-inch glass disk is being figured by Messrs Cox, Hargreaves and Thomson Ltd. The modified polar axis has been erected at Mt. Stromlo.

A mirror aluminizing plant with a 42-inch tank has been assembled and when certain leaks have been eliminated, it will be ready for operation.

*Liaison with other observatories.*—Arrangements have been made to provide facilities for other observatories at Mt. Stromlo. An invitation has been accepted by the Observatory of the University of Uppsala to erect a 16/26-inch Schmidt telescope in a dome to be provided by the Commonwealth Observatory at Mt. Stromlo. Further, the Southern Station of the University Observatories of Yale and Columbia is being transferred from Johannesburg to Mt. Stromlo. The principal instrument of the Yale-Columbia Station (a refractor of 26 inches

aperture) will be moved to a dome to be erected at Mt. Stromlo by the Commonwealth Observatory.

*General.*—Professor S. Chapman (Oxford) spent several weeks at the Observatory in January and gave lectures on terrestrial magnetism.

Professor D. Brouwer (Yale) delivered a series of lectures at Mt. Stromlo under the joint auspices of the Observatory and the Australian National University.

Dr Woolley has been appointed to the newly created Chair of Astronomy in the School of Physical Sciences of the Australian National University. He will, however, continue as Commonwealth Astronomer.

New staff quarters are in course of erection at Mt. Stromlo.

### *Riverview College Observatory, Riverview, N.S.W.*

(*Director, D. J. K. O'Connell, S.J.*)

The 1950 rainfall of over 83 inches was by far the heaviest since recording was started here in 1905, and the weather was exceptionally poor for observing. Nevertheless, three hundred and seventy plates were taken for the Variable Star programme. A considerable number of new variable stars, some fully worked out and others only partly studied, await publication.

*Publications.—Publication* No. 9 (Vol. 2, No. 5) was distributed during the year.

### *Sydney Observatory*

(*Director, Mr Harley Wood, Government Astronomer*)

The work on the *Astrographic Catalogue* has been continued and Volume 31 has been distributed. Volumes 29 and 32 are at present in the hands of the printer.

The occultations predicted in the *Nautical Almanac* have been observed when possible. The results for 1948 are published; those for 1949 are in the course of being printed and those for 1950 are reduced.

A new dome for the astrographic telescope, a photographic lens of 9 inches aperture, a coordinate measuring micrometer and a thermostatically controlled room are in the course of construction for the Observatory.

Two papers on Kepler's Problem by the Government Astronomer have been published and three more are to be published. These review the problem and give tables for application to parabolic or nearly parabolic orbits.

The civil work, consisting of the supply of astronomical information for legal purposes, time service and the answering of general enquires, has been carried on. The educational work of the Observatory was continued and lectures and demonstrations regularly delivered.

### *Radiophysics Laboratory, Sydney*

(*Director, Dr E. G. Bowen*)

In this first report a short background to the Laboratory's work on radio astronomy will first be presented. The Radiophysics Laboratory is a Division

of the Commonwealth Scientific and Industrial Research Organization, and is located in the grounds of the University of Sydney. It was founded in 1939 to carry out military radar development, but at the conclusion of the war it ceased to carry out investigations for the armed services and its programme was modified to provide a balance between fundamental and applied research. Radio astronomy was one of the fundamental researches selected.

Research in this subject began in 1945 with observations of radio waves from the disturbed Sun. These observations were prompted by reports of prior observations such as those of Hey. The work was greatly stimulated by our observations in early 1946 that the radiation came from small areas in the vicinity of sunspots and since then the disturbed Sun has been a major subject for study. In addition observational and theoretical investigations have been undertaken concerning the following :—

(1) In collaboration with the Commonwealth Observatory, studies of the radio waves emitted by the quiet Sun, leading to deductions concerning electron temperature and density distribution in the solar atmosphere.

(2) Observations of the discrete sources of cosmic radio waves—prompted by Hey's pioneer observation of the intensity fluctuations in Cygnus.

(3) Observations of the space distribution of the general background of galactic radio waves—leading to the inference of the existence of a spiral arm in the direction of Cygnus.

(4) Observations of the intensity of radio waves ($\lambda = 1{\cdot}25$ cm.) from the Moon—leading to a derivation of the sub-surface temperatures and the inference that the surface must be covered with a thin layer of thermally insulating dust.

(5) Observations of radio echoes from the Moon ($\lambda = 15$ m.) leading to the conclusion that these radio waves passing between Earth and Moon suffer a degree of obstruction, probably in the ionosphere, which is not adequately accounted for by the currently accepted model of that region.

There follows a list of the major series of observations now in progress :—

(1) Recording of solar radio wave intensity on wave-lengths of 3, 10, 25 and 50 cm.

(2) Observations of the apparent positions and polarization of sources of solar radio waves ($\lambda = 3$ m.) using a new form of interferometer giving a rapid response so that it can be used on highly variable components.

(3) Observations of the dynamic spectra of bursts of solar radio waves. A series of observations in the wave-length range 2–4 m. has been completed and equipment is being built to extend this range.

(4) A survey of the discrete sources of galactic radio waves visible in the southern hemisphere ($\lambda = 3$ and $1{\cdot}5$ m.).

Theoretical work is also in progress on the origin of galactic radiation, on the interpretation of the observed directional distribution of galactic radio waves in terms of the distribution in space of its sources, on the determination of the electron density and temperature distribution in the solar atmosphere from combined radio and optical observations and on the physical explanation of bursts of solar radio waves.

The greater part of this work is described in papers in the *Australian Journal of Scientific Research*, Series A, 1948, 1949, 1950, and a survey of the work on solar waves up to 1948 appears in the *Proc. I.E.E.*, Pt. 3, 1950 September.

### *Perth Observatory*

(*Director, Mr H. S. Spigl, Government Astronomer*)

The West Australian Standard time service has been maintained, and distributed by Onogo, hourly, and various other time signals.

The seismograph record is complete and records were distributed in quarterly bulletins to 45 cooperating stations. Preliminary data were cabled to the United States Coast and Geodetic Survey through the American Consul, relating to movements within 5000 km. of Perth. A number of original seismograms were despatched to assist in certain investigations.

Visits proved popular: on the average one afternoon and one evening per week were reserved for the general public, evening visits being particularly popular, and bookings generally some months in advance. The Government Astronomer also undertakes University lecturing.

Occultations were observed and results sent quarterly to the Nautical Almanac Office. Observations of sunspots by projection have been made and other astronomical phenomena observed.

Astronomical tables of various phenomena were distributed for a number of places throughout the State, and information for legal and general inquiries, and for the Press, was furnished when required. The tide tables for Port Hedland and the North-West coast incorporating astronomical data were completed and distributed.

### *Geophysical Observatory, Department of Scientific and Industrial Research, Christchurch, N.Z.*

(*Director, Mr J. W. Beagley*)

Since its establishment in 1948 December, the Christchurch Geophysical Observatory has been investigating relationships between geomagnetic disturbances and ionospheric activity. With ionospheric recording stations at Lincoln (N.Z.), Rarotonga (Cook Islands) and Campbell Island in addition to the magnetic observatory at Apia (Western Samoa) and the Magnetic Survey Base Station at Amberley (N.Z.), the observatory has at its disposal a wealth of data for such investigations. An examination of magnetic "crochets", radio fadeouts, "sudden commencements", the following geomagnetic disturbance and associated ionospheric effects covering the years 1947–49 has been made. Through the courtesy of the Director of the Carter Observatory, Wellington, who made sunspot and solar flare data available, it has been possible to include the solar aspect in the studies made at Christchurch. Results will be published shortly, while a note on the disturbance of 1949 May $10^{d}$ $20^{h}$ $04^{m}$ U.T., prepared in conjunction with the Director, Carter Observatory, has already been issued.

Information concerning disturbances on their radio circuits is obtained from the New Zealand Post and Telegraph Department and National Broadcasting Service as well as from the Superintendent, Apia Radio.

Data obtained by the Observatory are included in the *Cosmic Relations Bulletin* issued each month by the Radio Research Office of the Department of Scientific and Industrial Research of New Zealand.

*Canterbury University College, Christchurch, N.Z.*

(*Director, Dr C. Ellyett*)

A radar investigation of meteor occurrence in the Southern Hemisphere has been initiated by Canterbury University College, Christchurch, supported by a grant from the Department of Scientific and Industrial Research (N.Z.). Buildings have been erected at a new field station, and equipment is now being installed. The first objective of the new station, under the direction of Dr C. Ellyett, is to carry out a survey of the occurrence of Southern Hemisphere meteor showers.

*Carter Observatory, Wellington, N.Z.*

(*Director, Mr I. L. Thomsen*)

As in previous years the Observatory was open regularly to the public on Friday evenings from February to December for lectures and telescope demonstrations. Attendances totalled 2033. Two lectures on general astronomy illustrated by the film of "The Story of Palomar" were given in the Town Hall and attended by not less than 1100 people.

Sunspot observations have continued as in previous years and reports forwarded to Zürich Observatory. Studies of the latitude distribution in 1948 and 1949, and of the general solar activity from 1941 to 1949, were made and published in *Southern Stars*.

Forecasts of radio disturbances based on solar data were supplied to radio authorities as previously. It is believed that the first indications of M-regions were detected in the radio data.

Increase of general work reduced the amount of spectrohelioscope observing in the last half of the year, but this will be resumed again in 1951.

Micrometer measures of the diameter of Venus were made and after reduction will be published in *Southern Stars*.

Auroral work has been continued as outlined in the previous report. With the assistance of the Meteorological Bureau, auroral cameras connected by telephone have been installed on the aerodromes at Taieri and Invercargill. Up to date there have been no dual photographs, but very fine single station photographs have been obtained at Invercargill.

In the latter half of the year, some deterioration of one of the surfaces of the flint component of the 9-inch photovisual lens was noticed, and it was forwarded to Sir Howard Grubb, Parsons & Co., for refiguring. Until the lens is returned the Observatory is dependent on small instruments for observational work.

Monthly conferences were organized between representatives of the Post and Telegraph Department, National Broadcasting Service, Civil Aviation Department, Dominion Physical Laboratory and the Observatory for the study of solar and radio problems.

Information has been supplied to the Press, legal firms, architects and general enquirers as required.

*Seismological Observatory, Wellington, N.Z.*

(*Director, Mr R. C. Hayes*)

The astronomical work carried out by this Observatory during 1950 concerned only the maintenance of the Dominion Time Service.

The quartz clock, previously on test at the Dominion Physical Laboratory, was finally installed at the Observatory early in the year. Overseas radio time signals are now recorded in terms of the quartz clock and some large differences between the times of reception of Australian and American signals have been noted.

*Godlee Observatory, College of Technology, Manchester*

(*Curators, Manchester Astronomical Society*)

During 1950 routine solar drawings were made each day when weather conditions permitted, although long periods of cloudy weather considerably interfered with the work.

A number of lunar photographs were also taken.

On the educational side, facilities have been provided for parties from various societies, schools, youth organizations, and members of the public to visit the Observatory and inspect the instruments. On such occasions observational work has been carried out when weather permitted, and when this was impossible, lantern lectures were substituted. Some 500 persons availed themselves of these facilities. Many requests for astronomical lectures have been received from organisations in Lancashire and Cheshire. These have been provided as far as possible, and were much appreciated.

*The Observatory of Hampstead Scientific Society*

(*Astronomical Secretary, Mr H. Wildey*)

Over 300 visitors were entertained at the Observatory, many of these being fellows of the R.A.S. and members of the B.A.A. Observations of sunspots and prominences have continued, and planetary features have been noted and sketched with the 6-inch Cooke refractor.

*Mr F. Addey's Observatory, Long Sutton, Somerset*

Owing to illness no observations could be made from 1949 December 10 till 1950 May 11. During the remainder of 1950, 173 whole disk Sun drawings were made and four naked-eye spots were observed. All drawings and reports were forwarded to the British Astronomical Association.

*Mr R. Barker's Observatory, Cheshunt, Hertfordshire*

Although the diameter of Mars never exceeded 14 seconds of arc, and seeing conditions were often far from favourable, it was possible to obtain a few drawings of the surface markings. The North Polar Cap never entirely disappeared and " canali " in high northern latitudes were well marked and hinted at gemination in several cases. Certain new lunar physical markings by brother observers were confirmed, and in one case an extensive addition was made. The year was generally unfavourable for critical work.

*Mr J. Evershed's Observatory, Ewhurst, Surrey*

The liquid prism spectrograph has again been employed in testing the stability of the solar lines in the red region of the spectrum.

The measured wave-lengths of the solar iron lines in the region 6280–6318 when referred to the telluric lines in this region have, during recent years, always

yielded smaller values than the " recommended " wave-lengths given in Vol. III (1928) of the *Transactions of the International Astronomical Union*. I have recorded these measures in *Monthly Notices*, **108**, 347, 1948 and **109**, 594, 1949.

In the past year (1950) the measures of central disk spectra show a steady increase of wave-length, and the means for the year are very close to the International values for all the lines measured.

The total range of variation of the most sensitive line (6301) is over a hundredth of an angstrom, or on the scale of the spectra 0·02 mm., whilst the least variable line (6280) has not changed appreciably throughout the whole series of years from 1934.

### *Dr J. L. Haughton's Observatory, Charmouth, Dorset*

Owing to very unfavourable weather conditions only three occultations were observed during the year.

The observatory was open from time to time to members of the public. The Moon and various other objects were shown to about 70 visitors.

### *Mr M. B. B. Heath's Observatory, Kingsteignton, S. Devon*

Planetary observations were continued as follows :— of Mercury on 30 days with 5 drawings, of Venus on 15 days with 1 drawing, of Mars on 43 nights with 17 drawings and of Saturn on 46 nights when intensities of belts and zones were estimated, saturnicentric latitudes of belt edges being worked out for 19 of them, and on 29 nights when satellite magnitudes were compared.

Among the occasional phenomena observed were the fine display of aurora February 20, occultation of Spica (projection ½ second) March 7 and occultation of Jupiter's satellite II by satellite I December 11.

### *Mr F. M. Holborn's Observatory, Peaslake, Surrey*

(Lat. N. 51° 11′ 40″·03; Long. $+0^h\,01^m\,45^s{\cdot}4$ ; Altitude 140 metres)

The Observatory was moved to Peaslake from Streatham in 1950 May. During the year 1720 observations were made of 68 variable stars and 4 novae on 146 nights. The Sun was observed on 182 days for spot counts and naked-eye spots. Records were sent to the British Astronomical Association.

### *Mr Patrick A. Moore's Observatory, East Grinstead, Sussex*

As in previous years, observations have been confined almost entirely to the Moon. Areas near the limb have been under study, also certain formations showing dark interior bands. All results have been communicated to the B.A.A. Lunar Section, and as Secretary of that Section, Mr Moore has dealt with much correspondence.

The principal telescope is still an 8½-inch reflector, but this will be replaced by a 12½-inch reflector within the next month or so.

### *Mr F. J. Sellers' Observatory, Muswell Hill, London*

Observation of the Sun has been made on 156 days during 1950 with the 5-inch equatorial and spectroscope and/or the spectrohelioscope in connection with the 24-inch projected solar disk.

These observations have been recorded and reported as usual but no specially outstanding phenomenon has been seen. Solar activity has been at rather a low ebb during most of the year, especially since May, and observation conditions in London have been very poor during the latter part of the year.

### *Dr W. H. Steavenson's Observatory, Cambridge*

The 30-inch reflector has been used chiefly for photometric observations of novae. The results for 1948 and 1949 have been communicated to the Society. Observations of the satellites of Uranus have included measures of the position angle of Ariel and some photometric comparisons of the two outer satellites with stars near the planet's second stationary point. The results await the determination of the magnitudes of these stars.

### *Mr H. Wildey's Observatory, Hampstead, London*

The 12½-inch reflector has been used on the planets and in searches for new and suspected comets.

The Variable Star programme has been suspended because of the large amount of optical work in hand.

### *Mr H. P. Wilkins' Observatory, Bexleyheath, Kent*

Early in the year the 12-inch telescope was dismantled and the new 15-inch equatorial reflector mounted in its place. The mirror, by the late Mr W. McIntyre, is an exceptionally fine one and has given every satisfaction.

The instrument has been used principally for the detection of minute lunar detail, especially in the libratory regions which have been charted as a special section of the 300-inch map. A stereographic chart of the entire libratory regions, based on observations by the Director and P. A. Moore, has also been completed and published.

Mars was observed near opposition and on March 7, $21^h$–$21^h\ 30^m$, a minute moving point of light, close to the planet, probably Phobos, was glimpsed with the newly silvered mirror.

# REPORTS ON THE PROGRESS OF ASTRONOMY

## CELESTIAL MECHANICS

G. M. Clemence

Celestial mechanics, in its literal meaning, may be said to comprise all those branches of astronomy where the laws of mechanics find application; but by common consent it has generally been limited to applications of the laws of gravitation, thus dealing almost exclusively with the motions of celestial bodies, both translational and rotational. In strictness the subject dates from antiquity; in the modern scientific sense, however, it was founded by Isaac Newton. Although on the observational side it depends on astronomical observations through twenty centuries and more, it remained for Newton to organize and interpret the material; even today it is still the principal concern of most workers in the field to deduce the logical consequences of the laws of motion with which Newton was able to unify the whole body of knowledge of celestial phenomena that existed in his time.

It seems appropriate, for the purpose of this report, to restrict still further the meaning of celestial mechanics. The subjects of binary stars, stellar motions in general and galactic rotation, the motions of the external galaxies, and motions in the solar system, while all properly included in celestial mechanics, are best treated separately from one another. In the case of close binary stars gravitation is only one of the important forces that are acting, and when we consider general motions beyond the solar system statistical methods become necessary. It is only within the solar system that we are able to study gravitational phenomena in a way more or less pure and direct, and it is here that the theory has been developed to the highest degree of perfection. Furthermore, motions outside the solar system have been dealt with in these Council Notes in relatively recent years. This report therefore is confined, in the main, to the solar system.

In addition to drastically circumscribing the field we are about to survey, it is necessary practically to limit ourselves in time, in order not to become too prolix. Tisserand's *Traité de Mécanique Céleste* is so well known that it is not necessary to refer to subjects therein; accordingly we confine our notice virtually to developments in the first half of the twentieth century. The work of Le Verrier, Hansen, Newcomb, Delaunay, and much of that of Gyldén, Hill, and H. Poincaré, is passed over. We also emphasize the astronomical side of our subject rather than the mathematical, that is, we consider mainly the actual solar system in preference to hypothetical systems that have been extensively discussed; and we take the liberty of passing over a number of earlier contributions that seem now to be only of historical importance. Finally, we chiefly intend to mention only the contributions that are especially important, either for originality or completeness, thus overlooking perhaps nine-tenths of the significant work in the narrow field under discussion.

*Relativity.*—The most basic of the numerous developments of interest to us during the past half century was Einstein's formulation of the general theory

of relativity (1). This has been noticed in previous Council Notes, and the consequences from the standpoint of celestial mechanics have been worked out in detail by W. de Sitter (2). He finds that the well-known advance of the line of apsides (relative to an inertial frame of reference) is the only effect that can be observed. The immediate effect of the theory of general relativity was to remove the outstanding discrepancy between observation and theory then existing in the solar system: the non-Newtonian portion of the advance of Mercury's perihelion, discovered by Le Verrier. The corresponding effect in the motions of the other planets is much smaller; in fact it is commonly stated that the effect is perceptible only in the case of Mercury. No effect that increases with the time can, however, remain undetected for an indefinite time, and in point of fact the relativity effect in the motion of the Earth is now established (3); it will undoubtedly be perceived also in the motion of Mars after the Newtonian theory has been completed for this planet, and it should also be perceptible in the motions of certain minor planets.

The observation of the relativity effect in the Earth's motion proves the incorrectness of a procedure adopted by Newcomb, when his tables of the four inner planets were constructed. He assigned an increment to the Newtonian advance of the perihelion that was inversely proportional to the period of revolution of the planet, the factor of proportionality being determined by the observed advance of Mercury's perihelion. This way of proceeding is consistent with the supposition that the exponent of the reciprocal of the distance in Newton's law is slightly greater than two. In the case of the Earth it gives a result nearly three times as large as the relativity effect. Since Newcomb's procedure was not inconsistent with the observational evidence of his day, it may be said that the rigour with which the laws of gravitation are tested by observation has increased by a factor of at least three during the past 50 years.

General relativity has, however, more far-reaching effects than those just noted. It makes possible the practical realization of an inertial frame of reference (that is to say, the determination of the general precession in longitude) with a formal precision comparable to that of the determination by the analysis of stellar motions, and free from the systematic uncertainties of the latter. The principle is as follows. The gravitational theory of the motion of the planet is referred to an inertial frame, whilst the observations are referred to the rotating equinox. In order to reconcile the two the precession must be known. If the assumed value of the precession is incorrect, then the residuals O–C in the longitude contain a periodic term, with period equal to the planet's revolution and known phase; the amplitude of this term increases proportionally to the time, and is easily interpreted as a correction to the assumed value of the precession. It may be objected that, since the planet's position at any time is determined with reference to stars in the immediate neighbourhood, systematic errors in the assumed proper motions of these stars may produce spurious periodicities of the kind we are seeking. This objection would have weight, were we confined to the perihelion of a single planet. But by choosing a number of planets with perihelia suitably spaced around the sky we can eliminate any systematic errors of the proper motions from the results. Furthermore, we are not limited to the perihelia; the nodes provide an equally good means of determining the precession. This method, first attempted by

Anding (**4**), and later by Bauschinger (**5**), has not yet been fully exploited, owing to the very considerable amount of calculation required. The latest application is by Brouwer (**6**) who, by analysis of the motions of Mercury and the Earth, obtains a value having an uncertainty three and a half times that associated with the analysis of stellar motions. This result promises well for the precision of the more extensive work planned on the subject for the near future.

In connection with the determination of the precession, W. H. Wright's (**7**) proposal to use the external galaxies as an inertial frame of reference is of fundamental importance. The project was initiated by Wright in 1934, and observations were commenced about 1946 by Shane. The first survey of the portion of the sky that can be seen from the Lick Observatory is rapidly approaching completion. It will be necessary to repeat it after waiting long enough for the precession to reach measurable proportions, perhaps 30 to 50 years or more.

*The problem of three bodies.*—Tisserand remarked in his treatise " La solution rigoureuse du problème des trois corps n'est pas plus avancée aujourd'hui qu'à l'époque de Lagrange, et l'on peut dire qu'elle est manifestement impossible ". Whether this statement remains true today depends on the meaning attached to *rigoureuse*. If by a rigorous solution is meant an explicit development of the relative coordinates of three bodies as functions of the time, which converges for all values of the time, the statement still holds, at least if no restrictions are placed on the motions. Sundman's epoch-making work (**8**) has shown, however, that in a more general sense, the general problem of three bodies has a solution. Let us imagine that the nine coordinates of three bodies are expressible in terms of a variable $\tau$, in series that converge for $-1<\tau<+1$; imagine further that the time is also expressible as a function of $\tau$, converging in the same domain, and that, as $\tau$ varies from $-1$ to $+1$, $t$ varies from $-\infty$ to $+\infty$; imagine further that definite rules are given for calculating any term of the series when the initial conditions are known. If these three conditions are fulfilled the problem may be considered solved, because to any value of $t$ corresponds a definite value of $\tau$, and to any value of $\tau$ correspond definite values of the coordinates. Sundman has shown that the three conditions are actually fulfilled, under the laws of Newtonian mechanics. Birkhoff has concluded that the work of Sundman can be extended to $n$ bodies. Many attempts have been made to apply the series of Sundman to the calculation of the actual motions of bodies in the solar system, without success. Even if this could be done, the calculations would certainly fail to represent the positions of the actual bodies over a very long time, for other forces than those of Newtonian gravitation are certainly acting in the solar system, and the theory of general relativity must have important implications here, although what these implications are no one yet knows.

The so-called restricted problem of three bodies is the special case where two of the bodies revolve in circles around their centre of gravity, and the third body, of negligible mass, moves in the same plane. Under an infinite number of special values of the initial conditions, the orbit of the third body is periodic, that is, the body describes a closed curve in the rotating plane in which the finite bodies are fixed. Hill (**9**) was the first to develop a practical method of elaborating the lunar theory to high accuracy by using the periodic

solution known as the variation orbit as the first approximation; and he indicated methods for obtaining other classes of periodic orbits. G. H. Darwin (**10**), Moulton and his students (**11**), E. W. Brown (**12**), E. Strömgren (**13**) and many others have studied periodic orbits by various methods, but as yet only a few of the possible types have been determined. Poincaré (**14**) suggested that every orbit may be approximated for an arbitrary length of time by a periodic orbit, but this statement has been neither proved nor disproved. Birkhoff (**15**) has, however, shown that every stable orbit has either certain properties of recurrence, or asymptotically approaches to and recedes from orbits with such properties. In general it may be said that periodic orbits, while of a high degree of theoretical interest, have not proved to be of much practical value in studying actual motions in the solar system; even in the case of the Moon it may be doubted whether the variation orbit in the first approximation is really superior to the Keplerian ellipse, so far as the labour of the numerical developments is concerned.

*Lunar theory.*—The completion of E. W. Brown's theory (**16**) of the motion of the Moon, constructed on principles indicated by Hill, and the construction of tables based on it by Brown and Hedrick, constitute the greatest achievement in this field during the present century. Since 1923, when they were first used, the tables have been minutely compared with observations of the Moon, both meridian observations and occultations, and there can hardly be any doubt that Brown reached the goal he set for himself. It is the general rule, however, in work of this kind, that insufficient provision is made for the requirements of the future, which often demand increasing accuracy. These shortcomings are not an evil, but are a necessary result of the fact that astronomers are not seers. The tables of the motion of the Moon are no exception to the rule; for the most exacting work, such as the general use of eclipses and occultations for geodetic triangulation, they are insufficiently accurate. The same is not necessarily true of the theory itself; at least formally, the theory is capable of yielding positions of the Moon considerably more accurate than the tables are. W. J. Eckert has recently begun to calculate an ephemeris of the Moon directly from the series expressions for the coordinates, using the selective sequence electronic calculator of International Business Machines Corporation. The first results have been compared in detail with the tables by E. W. Woolard, and the comparison, as yet not quite complete, has brought to light a number of inadequacies in the tables, which probably are not due to any oversight, but to a deliberate effort to minimize the labour required in using the tables. It seems likely that Eckert's ephemeris will suffice for all present needs.

Brown's lunar theory has one limitation, of no consequence in geodetic work, but of interest in connection with the figures of the Earth and Moon. The motions of the perigee and node are given by the theory with less accuracy than the observations give. Eckert has done a considerable amount of work on a numerical verification of the solar portion of Brown's theory, along lines previously indicated by Airy (**17**), which, if completed, will lead to improved theoretical values of the motions.

*The rotation of the Earth.*—Among the most important consequences of the lunar theory of Brown is the light it has thrown on the rotation of the Earth. It was first suspected by Lalande (**18**), on theoretical grounds, that the speed of rotation might vary. An undetected acceleration of the rate of rotation will,

of course, cause the Moon to appear to be retarded in its orbit, as compared with the position predicted by theory. It has been the universal experience of all who have elaborated theories of the motion of the Moon, that the Moon failed to abide by them, and the discrepancies were commonly ascribed to inadequacies of the theories, usually with justice. Newcomb, however, was much impressed with the possibility that the Earth might be at fault, and not the lunar theory; and he devoted much attention to the subject, without success. Any apparent fluctuations in the motion of the Moon, that are really due to variations in the speed of the Earth's rotation must, of course, be accompanied by similar fluctuations in the orbital motions of all other celestial bodies, which are, however, reduced in the ratio of their mean motions to that of the Moon. Newcomb's failure was due in part to the relatively poor quality of the planetary and solar observations at his disposal, in part to the near uniformity of the speed of rotation during the period covered by the best observations, and in part to doubts concerning the quality of the lunar theories of his day. Brown's confidence in his own theory was at first not complete and, like his immediate predecessors, he inserted an empirical term into the tables of the Moon, with the object of bringing the tables into approximate agreement with past observations. Continued study of the theory, however, brought him to the conclusion that no defect of the required size could exist in it, and at last he became convinced that the observed discrepancies must be due to variations in the speed of rotation of the Earth. Quantitative discrepancies remained, however, and W. de Sitter found it necessary to introduce a factor of proportionality, different from the ratio of the mean motions, to bring the observations of the Sun, the planets and the Galilean satellites of Jupiter, into agreement with those of the Moon. It remained for Spencer Jones (**19**), by a rediscussion of meridian observations of the Sun and Venus and transits of Mercury, to remove the remaining doubts, and to show conclusively that the observed fluctuations in the motions of the Moon and all these bodies are, in fact, proportional to their mean motions or, in other words, that they are due to variations in the speed of rotation of the Earth. The slow retardation of the Earth's rotation, due to tidal friction, produces a real acceleration of the Moon's angular mean motion (conserving the momentum in the Earth-Moon system) in addition to the apparent effect. This real acceleration, not shared by the planets, is not taken into account in Brown's theory, and must in any case be determined by observation, because geophysics is not yet equal to the task of calculating the energy dissipated by the tides with sufficient precision.

Stoyko (**20**), Scheibe (**21**) and Finch (**22**) have independently established an annual variation in the speed of the Earth's rotation, which produces irregularities in the measure of mean solar time as great as 60 milliseconds. The cause is undoubtedly meteorological in origin, and van den Dungen, Cox and van Miegham (**23**) have shown that it may be due, at least in part, to transfers of energy between the atmosphere and the solid earth. Whether incomplete compensation of these effects can account in addition for the fluctuations is not known.

The result of all this is to show that the mean solar day is not suitable for use as the fundamental unit of time. The mean sidereal year is a better unit, which has already been used to some extent, and it may before long be officially adopted.

The polar motion (Eulerian nutation), first observed by Küstner, was firmly established by Chandler (**24**) late in the nineteenth century, and it was shown by Newcomb (**25**) that the period of the free oscillation could be used to determine the rigidity of the Earth as a whole. The period and amplitude both change rather abruptly from time to time; correlation of these effects with changes in the speed of rotation and with earthquakes have both been shown, and it is probable that the causes are meteorological, at least in part.

*Generalized planetary theory.*—As is well known, the solar portion of the lunar theory has been brought to a high degree of formal perfection. Methods are known for obtaining numerical expressions for the solar perturbations of the coordinates, which can be evaluated for any time whatever, and which therefore have a certain degree of validity for all time; and these methods have actually been successfully applied to the motion of the Moon. They depend on expansions in powers of the ratio of two distances (approximately the distances of the Moon from the Earth and Sun), and they cannot be applied to the planetary problem, on account of the large value of the corresponding ratio, which makes the series converge with extreme slowness. Poincaré (**14**) and Gyldén (**26**) both indicated methods that might overcome this difficulty, but no complete numerical application of them has yet been made. Toward the end of his life Hill (**27**) gave much attention to the problem, and several of his later papers deal with it. He proposed to treat the matter by successive approximations, first considering Jupiter and Saturn, alone and moving in the same plane, intending later to take account of the inclination and the other planets. He elaborated the formulae with some degree of completeness, and went so far as to obtain the first numerical approximation to the terms of longest period for Jupiter and Saturn, that is, the principal terms that contain the motions of the perihelia in their arguments. For the general integration he experimented (**28**) with the method of Delaunay's lunar theory.

In 1947 Brouwer was led to make some important modifications (as yet not published) in Hill's method, with a view to adapting it to automatic calculating machines and to obtaining a method of successive approximations proceeding in powers of the masses, in which a repetitive process would be used, substituting into the formulae at each stage the complete orbits as they resulted from the preceding stage. A considerable amount of numerical work has been done under Eckert's direction, but it is as yet too early to say whether the convergence will be sufficiently rapid to bring the work within the scope of calculating machines now available, or whether additional modifications must be made in the method. The magnitude of the undertaking can be imagined if we remember that Hill's numerical expressions for the coordinates of Saturn, in the classical form, comprise periodic terms with about 200 different arguments; in the generalized theory the number required may approach the square of this.

The question of the convergence of the series used, both in this generalized theory and in the classical planetary theory, is an important one. Poincaré (**29**) has asserted that the series for the coordinates obtained by integration are in general divergent, when no restrictions are placed on the initial conditions, if the mean motions of two of the bodies concerned are incommensurable with each other. Hill (**30**) has, however, proved that the series converge for all finite times if the ratio of the mean motions is an irrational root of an algebraic equation

with rational coefficients. Since the observed ratios can be approximated in this fashion as closely as desired, there is no obvious way of deciding the question of convergence in the case of the large planets of our system. There is nothing to prevent our supposing that the series may converge, at least in the limited domain of initial conditions and masses within which our planets are known to be. Even if this should be so, it would, however, prove nothing about the permanence of the actual system, owing to the presence of other forces than Newtonian gravitation.

The secular perturbations of the principal planets have been recalculated by Brouwer and van Woerkom (**31**), following Harzer (**32**), but with improved values of the masses and a more rigorous treatment of Jupiter and Saturn. They have extended the results by calculating tables showing the approximate secular perturbations of minor planets as functions of the major axes. These are useful in discussing the Hirayama (**33**) families of minor planets, and Brouwer (**34**) has thereby considerably increased the number of known families. It can hardly be doubted that (as many have supposed, but only Hirayama and Brouwer have established computationally) each family of minor planets originated in a disruption of a larger body. Kuiper's (**35**) theory of collisions appears to furnish a satisfactory mechanism.

*Classical planetary theory.*—By classical planetary theory is meant the usual form of general theory, in which the time and its positive integral powers are permitted to appear outside the trigonometric functions of the angular arguments. The most important advance in this field since the time of Hansen has been made by Brouwer (**36**). His method, like the others, is one of successive approximations along powers of the masses. Instead of calculating at each stage the increments of the perturbations already obtained, due to the corresponding increments of the disturbing forces, he proceeds by a repetitive process, in which at each stage the perturbations already obtained are substituted in the right-hand members of the equations for the perturbations, which then yield improved values, valid to one higher order of the masses than before. In consequence, the calculation of the perturbations of higher order than the first is greatly simplified. In addition to this important advantage, his developments possess an unusual degree of symmetry, due to the use of canonical variables in the factors that multiply the disturbing forces, together with the use of rectangular coordinates. The symmetry is obtained at some sacrifice of brevity in the numerical development of these factors, which renders Hansen's method the readier one if it is proposed to stop with the first approximation, and which to some extent counterbalances the advantages of the new method in the second approximation. There is no doubt, however, that in the third and higher approximations the new method is preferable to all others. Its use would be indicated if new theories of the outer planets were to be constructed and, in most cases where it is applicable, if it were desired to obtain a general theory of a minor planet comparable in precision with the observations.

The group theory of Bohlin (**37**) is of fundamental importance for the practical calculation of the approximate Jupiter perturbations of minor planets having mean motions nearly commensurable with that of Jupiter. His method is a modification of Hansen's and is general for all groups, with special application to the group 1/3. The method has been followed by von Zeipel and by

Leuschner, Estelle Glancy and Sophia Levy (McDonald) in application to the group 1/2, and by D. F. Wilson to the group 2/5.

Brendel's modification (**38**) of Gyldén's method, in which the long-period perturbations are determined at an early stage of the work, aims at representing the positions of minor planets with a precision of 20 minutes of arc for 100 years. Brendel, Lebitzke and Boda have successfully applied the method to some 230 minor planets.

The methods of Bohlin and Brendel are not applicable to the Trojan group, owing to the special character of the motion of the Trojan planets, which librate about the equilateral points with Jupiter and the Sun. Wilkens (**39**) has developed a method for representing the motion of a Trojan planet satisfactorily from one opposition to the next, while E. W. Brown (**40**) has devoted attention to the problem from a more general point of view. Methods developed by Brown have been applied to particular planets by Eckert (**41**) and Brouwer (**42**). Brown and Shook (**43**) have indicated a method of approach to a group theory of the Trojan asteroids, and Hertz (**44**) has carried out the details of the development.

Among the applications of classical planetary theory to particular minor planets, the work of Leveau (**45**) on Vesta and of Osten (**46**) on Valentine deserve special mention on account of their exhaustive character. Leveau has studied the motion closely over an entire century, while Osten has pushed the approximations to the third-order perturbations by Jupiter and Saturn.

Despite all the care and labour that has been lavished on the elaboration of general planetary theories since the time of Laplace, we have as yet no example where the motion of a single planet has been calculated as accurately as it has been observed. It is true that in many cases this goal has not been aspired to, but it must have been in the minds of at least Le Verrier, Hansen, Hill, Newcomb, Leveau and Osten. It is the writer's conviction that the failures are not due to any fundamental defect in the methods, but in part to the very great labour required, which impels the computer to abridge the developments as much as possible, sometimes too much, and in part to numerical mistakes. Modern calculating machinery should provide insurance against both of these evils in future work of this kind.

*Numerical theory.*—In the period under review the most significant advance in the field is undoubtedly the development of the method known to astronomers as Cowell's, first used by Cowell and Crommelin (**47**) in calculating the motion of Halley's comet from 1759 to 1910 in preparation for the 1910 return. The merits of the method are its simplicity, its rigour and its brevity, the perturbed rectangular coordinates being obtained directly with as much precision as is desired. The most efficient use of the method requires the rectangular coordinates of the disturbing planets to be already available, and this need has now been supplied by the (British) Nautical Almanac Office, at first by Comrie in the volumes *Planetary Coordinates*. Since the publication of the first of these volumes the method has been much used for minor planets and comets over a relatively small number of revolutions. Like all numerical methods, it demands a considerable amount of figure work, which increases proportionally to the three-halves power of the time-interval involved and also very rapidly for close approaches to disturbing planets and to the Sun; hence the power of the method depends on the power of the mechanical aids at hand. The

first application was the most extensive before the advent of calculating machines. With desk calculators the most extensive application is that of Grosch (**48**) to Jupiter's eighth satellite. Recently, using punched cards, Herget (**49**) has integrated the motions of Ceres, Pallas, Juno and Vesta with high precision from 1920 to 1960. The method attains its greatest power with a large electronic calculator, and it seems better adapted to such a machine than any other known method. During the past three years Eckert, Brouwer and Clemence (**50**) have integrated the motions of the five outer planets over the 407-year interval 1653 to 2060, with actually greater precision than the observations are capable of giving, using the selective sequence electronic calculator of International Business Machines Corporation. In this work, for the first time, the mutual attractions of all the planets involved were calculated at every step; and the coordinates were calculated to 14 places of decimals, this large number being required by the accumulation of errors of rounding over the 2600 steps from the initial epoch. The detailed comparison of these integration orbits with observations may be expected to yield much of interest. In addition, there are now available for the first time coordinates of the outer planets of requisite accuracy for the precise integration of minor planets and comets over many revolutions.

Among other rigorous methods should be mentioned Merton's (**51**) and Herrick's (**52**) modifications of the method of perturbations of elements. The former is well adapted to speedy calculation with auxiliary tables, and both may be suitable for use with large electronic calculators. It should be mentioned, however, that Herrick's claim for reduction of the influence of errors of rounding is without foundation, as he himself is now convinced.

Valuable tables for facilitating the calculation of approximate special perturbations have been published by Crommelin (**53**) and by Stracke (**54**). The aims here in view are the severely practical ones of calculating search ephemerides of periodic comets and minor planets, to prevent their being lost, with the minimum amount of labour.

*The principal planets.*—Observations of the Sun during the present century have been thoroughly discussed and compared with Newcomb's tables by Morgan and Scott (**55**). Similar work for Mercury has been done by Clemence (**56**), and for Uranus and Neptune by L. R. Wylie (**57**). In progress are discussions for Venus by Duncombe, and for Jupiter by Hertz. The results have confirmed the relativity effects in the motions of Mercury and the Earth, and also have confirmed Newcomb's theories of these two planets in a general way. There remain, however, small systematic discrepancies between observation and theory, which it is difficult to account for in any other way than by supposing the theory to be inadequate. This is definitely known to be the case for Mars (**58**), where the defects are of such a nature as largely to nullify the usefulness of the theory. The theory of Mars is being reconstructed by Clemence (**59**), and the first-order portion is completed. Jupiter, Saturn, Uranus and Neptune are all departing from the tables of Hill and Newcomb by increasing amounts. In the case of Jupiter and Saturn, comparison of the tables with the numerical integrations recently completed show clearly that Hill's determination of the great inequality, and of the secular perturbations, was incorrect; and that in addition, other defects of a more complicated nature are present in his theory. For Uranus and Neptune, a similar comparison

shows that Newcomb's determination of the synodic perturbations is at fault, and, of course, his necessary neglect of the action of Pluto has its effect.

The discovery of Pluto at the Lowell Observatory in 1930 was immediately followed by much discussion of the question whether its location near the place predicted by Lowell should be regarded as a second triumph of celestial mechanics in this field, or as an accident. Crommelin (**60**) has reviewed the position in a Council Note. Subsequently the subject was further studied by E. W. Brown (**61**) and by Kourganoff (**62**). The question turns to a considerable extent on the smallness of the perturbations of Uranus by Pluto, which are, of course, proportional to the mass of Pluto. Some investigators may have been misled by supposing that the mass of Pluto, and hence its action on Uranus, was smaller than it really is. But there is no question that, even at best, the perturbations are very small, and become entangled to some extent with the accidental errors of the observations and with the defects in the theory of Uranus. In these circumstances it is difficult, if not impossible, to prove beyond a possible doubt that Pluto is actually the planet predicted by Lowell, since it is always possible that errors in theory and in observations may combine fortuitously to give fictitious indication of a planet. Further, it is possible for a real planet to exist very near the fictitious indication. It seems to the writer, however, that the balance of probability would lie heavily in favour of the reality of Lowell's prediction, even if he had done no more than indicate the right ascension and declination of the unknown planet. Taken together with his prediction of the very high inclination of the orbit, the case would seem at least to be proven beyond a reasonable doubt, provided that the mass of Pluto is comparable with that of the Earth, as has been indicated by its action on Neptune (**63**) and Uranus (**62**). On the other hand, if Kuiper's (**64**) determination of the diameter of Pluto should prove to be correct, then it would follow either that the gravitational determination of the mass is greatly in error, or else that our ideas of the relation between mass and diameter must be drastically revised.

In connection with the determination of the mass of Pluto it is of interest to notice that owing to the high inclination and the position of Pluto in its orbit, the latitude perturbations of Neptune are comparable with the longitude perturbations, a case unique in the solar system, which was evidently not recognized by Lowell.

*Satellites.*—The first half of the twentieth century has seen the number of known satellites in our system increased from 22 to 30, with the discovery of six additional satellites of Jupiter by Perrine (2), Melotte (1) and Nicholson (3), and one each of Uranus and Neptune by Kuiper.

Sampson (**65**) developed tables of the Galilean satellites of Jupiter after a theory of his own (**66**), which with some modifications by Andoyer (**67**) remain in use today for predicting the phenomena. W. de Sitter did a considerable amount of work on a new theory, pushing the approximations to a new degree of precision, but left it incomplete, and the subject has recently been taken up again by Brouwer.

Woltjer (**68**) has investigated the motion of Hyperion extensively.

The most extensive study of the satellites of Mars to date is that of H. Struve (**69**) early in the century, who also gave some attention to the two outer satellites of Uranus (**70**). Woolard (**71**) has recently contributed to the theory of the motion of the satellites of Mars.

Ross (**72**) applied Delaunay's lunar theory to the sixth and seventh satellites of Jupiter, with indifferent success, since, as he himself recognized, it is inadequate for satellites with motions of this character.

Alden (**73**) has determined the mass of the satellite of Neptune by the inequalities it produces in the motion of Neptune, determined photographically.

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With the exceptions just noted, little has been done beyond a few determinations of elliptic elements, with in some cases their observed secular variations, although the study of satellite motions is a very rich field of investigation. Two important conclusions have, however, been recently obtained. Sharpless (**75**) found that the inner satellite of Mars has a marked secular increase in its mean motion, and van Woerkom (**76**) later found the same effect, to a less marked degree, in the motion of the fifth satellite of Jupiter. The cause remains unexplained.

*Comets.*—A number of investigations, especially those of Fayet (**77**) and E. Strömgren (**78**) have shown the complete lack of evidence for the existence of comets that enter the solar system in other than elliptic orbits.

Van Woerkom (**79**) has come to some important conclusions regarding the motions of comets. He has studied the action of Jupiter on long-period comets entering the solar system from a distance, and he shows that the observed distribution of the major axes can be satisfactorily explained by this action. He also shows that if the long-period comets come from interstellar space, the field in which they lie must move with the Sun, that they cannot have been captured recently by passage of the Sun through an interstellar cloud, that they cannot have stable orbits, that if they have always belonged to the solar system, the forces within the system cannot account for the observed phenomena, and that they cannot have erupted from one of the large planets. He also finds evidence to support the view that the short-period comets may have been captured by Jupiter from long-period orbits.

Oort (**80**) finds that the Sun is surrounded by a general cloud of comets with radius 50,000 to 150,000 astronomical units, estimating the number to be about $10^{11}$ and the total mass $\frac{1}{10}$ to $\frac{1}{100}$ that of the Earth. Through the gravitational action of the stars comets are carried from this cloud into the vicinity of the Sun. He suggests that the cloud may have originated at an early stage of the solar system, through the perturbing action of Jupiter and the stars on escaped minor planets. The possibility of such a cloud of comets was mentioned earlier by Russell (**81**) following a suggestion of Öpik (**82**).

Whipple (**83**) has developed a comet model which suffices to explain the observed secular changes in the mean motions of short-period comets on the basis of loss of mass by evaporation whilst the comet is near the Sun. Such evaporation can either increase the mean motion and decrease the eccentricity, or the reverse, depending on the sense of rotation of the comet.

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## MINOR PLANETS

The minor planet programme has continued in a satisfactory manner during the year since the last report. Observing activity has proceeded at a pace which must be accepted as normal and good. The arrangements for ephemeris computations of the numbered planets have been satisfactory, and it is expected that the next volume will appear several months earlier than last year. A definite acceleration has been achieved in the number of improved elements which have been determined.

The Institute of Theoretical Astronomy at Leningrad again produced a complete ephemeris volume for the year 1951, and the introduction gives an insight into the progress of the work there. New elements are given for 44 planets. For 202 of the planets which were assigned to the I.T.A. for ephemeris computation and which have mean daily motions less than 700″, the Jupiter perturbations are now being computed in rectangular coordinates by means of punch-card machines. Comparisons with observations are given, and in all probability improved elements will be determined as required. In addition, there are 69 other planets which were computed with special perturbations, and 37 which were computed with general perturbations.

The Rechen-Institut at Heidelberg has published a complete volume of *Elemente und Grundlagen der Kleinen Planeten* during this past year. This volume will now be used as a standard reference and basis for the elements of all the minor planets. In the future, according to a resolution of Commission 20 of the I.A.U., any change in the elements upon which the ephemeris in the annual volume is based will be published in an appendix during the first year in which they are used. In subsequent years there will be a reference, showing the year in which these elements were published. The Rechen-Institut has also computed improved elements for 22 planets with, and 12 planets without, special perturbations.

The cooperative programme inaugurated at the Cincinnati Observatory is becoming more fruitful. Nearly a dozen institutions or individuals are using the perturbations computed by means of punch-card machines in connection with the orbit improvements they are making. More cases are on hand if others would like to join in this work. There were 146 Minor Planet Circulars issued during the year.

On the observing side, the searches made for planets on the critical list continue to be successful. Seventy-one planets were removed from the list, of which 23 had not previously been observed in four oppositions. The total list was diminished by only 35, because of the addition of some other planets which had not been observed during the last ten years. A total of 343 provisional designations were assigned during the year. A report from the Goethe Link Observatory of the University of Indiana, which was not engaged in minor planet observing prior to 1947, shows the contribution of this new observing station. To date they have recovered 81 objects on the critical list, failed to find 39 after a search, and observed 165 other known minor planets and 366 new or unidentified objects. The observatory at La Plata has also considerably increased its contribution to minor planet observing and computing. These

contributions probably compensate for the loss sustained from some observatories formerly engaged in this work which are no longer able to continue.

The discovery of unusual objects has lessened. However, two Trojans were discovered at Heidelberg, but not securely observed. Another Trojan discovered at Uccle is still under observation and seems to be more secure. (1566) Icarus = 1949 MA has been observed in a second apparition and seems to be secure. Two other planets have been assigned numbers, and there are quite a few which have been observed sufficiently and need only to have good elements computed from all the observations in order to receive numbers. The wisdom of this requirement is indirectly attested by the discovery during this last year that (919) Ilsebill has had erroneous elements ever since 1918, simply because there was not an exact comparison with the observations which existed in just that one year, and one of the observations was in error. Some other numbered objects, such as (1095) Tulipa, also are known to depend on insufficient or inconsistent observations.

A project is under way to prepare a volume dealing with the origin and meaning of the name of each minor planet and the reason why it was assigned by the discoverer, or what is the intention of the honour. For example, HAPAG is the initials of Hamburg Amerika Paketfahrt Aktien Gesellschaft, and it was so named after some astronomers were transported (perhaps at reduced rate) to a meeting in Bergedorf. ARIBEDA is a concocted name standing for Astronomisches Rechen-Institut of BErlin DAhlem. A substantial contribution to this project has been submitted by Senor A. Paluzie, a librarian of Barcelona, Spain, but information of this kind from others will be welcomed. In the future such information will accompany the first printed announcement of each new name.

On the whole, the minor planet work during this past year shows an encouraging improvement over the previous year. The remark about the Rechen-Institut in the first paragraph of last year's report is entirely false, according to Professor Kopff. He states that the minor planet material at Heidelberg is complete and that only three of twelve staff members remained in the Russian zone.

PAUL HERGET.

## SOLAR ACTIVITY

*Sunspots.*—A curious feature of this post-maximum year was the drop in sunspot frequency after August, together with a marked lapse of solar flare occurrence and of chromospheric activity in general. These inactive conditions, which were strongly reflected in the state of the ionosphere related to ultra-violet solar radiation, can be regarded as temporary, since sunspot maximum was passed only three years ago (1947·5).

Paradoxically, throughout this apparently subnormal period, there was appreciable recurrent $F_2$-layer disturbance, synchronizing with a well-developed 27-day sequence of small geomagnetic storms, each lasting for about a week and commencing respectively on August 7, September 3, September 30, October 28, November 24 and December 22. Solar M-regions presumed responsible for

sequences of geomagnetic storms, such as the present sequence, are especially noticeable in the declining and minimum phases of the sunspot cycle.

The provisional mean daily sunspot "number" ($R$) for 1950 is 83, as compared with 134·7 for 1949 and 151·6 for the maximum year of the present cycle. Although this value of 83 is little more than half that of the peak year of this extraordinary cycle, it equals that of some maxima, e. g. 1928, 1905 and 1883. It is therefore perhaps not surprising that in 1950 spot groups with maximum area of 500 millionths of the Sun's hemisphere and upwards averaged rather more than two per month. The striking feature about the majority of these groups was their subnormal activity. This is supported by the greatly diminished frequency in daylight hours of (*a*) radio fadeouts (synchronous with the more intense solar flares) recorded on short-wave long-distance communication; (*b*) sudden anomalies in the reception of very long radio waves, which mark even the minor flares; and (*c*) geomagnetic crochets; and also by extended periods when bursts of solar radiation observable on radio wave-lengths were very infrequent or entirely absent. With respect to (*c*), no important crochet was recorded at Abinger throughout the year. A small crochet ($\Delta H = 10\gamma$) is probably shown on the magnetogram on April 12 at $14^h\ 54^m$ U.T. synchronous with a flare of importance 3 described in *The Observatory*, **70**, 164, 1950.

For size and perhaps activity, the outstanding spot group was that with central meridian passage on February 20. Its association with a *great* geomagnetic storm of that date is briefly reviewed in *The Observatory*, *loc. cit.*, p. 163. This spot group in latitude 11° north and of type $\beta\gamma$, attained an area of about 2800 millionths of the Sun's hemisphere. Both in the previous and following rotations, there were sunspots representing entire or partial continuity of disturbance in the same solar region. It is of interest that small geomagnetic storms began 27 days before and 27 days after the onset of the great storm and auroral display of February 20–22 (S.C. onset February 19 at $23^h\ 40^m$ U.T.). But this 27-day sequence, associated in a more or less distinctive manner with solar flares and bursts of solar "noise" appears to be of a different character from the marked 27-day sequence of small storms previously mentioned.

In connection with the latter sequence (M-region origin) it may be noted that while solar "noise" on metre wave-lengths was subnormal during the recurring geomagnetic storms, it was strongly abnormal from June 13 to 18, i. e. exactly two solar rotations before the geomagnetic sequence became established. This very active period of solar "noise" was apparently associated with a sunspot crossing the central meridian on June 14, but subnormal in flare occurrence, like other spots of this general epoch.

H. W. NEWTON.

*Prominences.*—Prominence activity during the year under review shows considerable decrease as compared with the previous year. The mean daily areas and numbers of calcium prominences as derived from photographs taken at Kodaikanal are given below :—

| | North | South | Total |
|---|---|---|---|
| Area (sq. minutes) | 1·54 | 1·04 | 2·58 |
| Number | 4·48 | 3·52 | 8·00 |

Compared with the previous year's values, the areas and the numbers show 37 per cent and 26 per cent decreases respectively. The latitudinal distribution of areas indicates maximum activity in the zones N. 25°–35° and S. 20°–25°, with two secondary maxima at N. 65°–70° and S. 55°–60°. A comparison with the distribution of areas and numbers in 1949 indicates no marked change.

Twelve metallic prominences were observed with the prominence spectroscope. Eleven of these were in the northern hemisphere and one in the south. Nine were observed on the east limb and the rest on the west limb.

Doppler displacements of the *H*-alpha line in prominences were observed on 45 occasions with the prominence spectroscope. In 14 cases the shifts were towards red, in 11 cases towards violet and on the rest of the occasions in both directions. Particulars of a few prominences which showed large Doppler shifts are given below :—

| Date | Coordinates of prominences | Doppler displacements observed |
|---|---|---|
| February 3 | W. limb—N. 10° | 3 A. to violet } same prominence |
| | W. limb—N. 14° | 4 A. to red } |
| March 13 | E. limb—N. 20° | 4 A. to red |
| March 15 | W. limb—N. 30° | 3 A. to violet and 3 A. to red |
| May 4 | E. limb—S. 10° | 3 to 4 A. to red and 1 A. to violet |

There were nine occasions during the year when sudden disappearances of fairly large hydrogen absorption markings on the disk and prominences on the limb were noticed. A large eruptive prominence was observed on February 3 at mean latitude S. 2°·5, extending over 32° on the west limb and covering an area of 8 sq. minutes of arc. Large Doppler displacements indicating great agitation were noticed before the prominence erupted. The maximum height of the prominence as recorded on the calcium spectroheliogram taken at $05^h\ 42^m$ U.T. was 630 seconds of arc or nearly 285,000 miles.

The heights of 98 prominences were measured with the prominence spectroscope in *H*-alpha, $D_3$ and *H*-beta lines. These were compared with the heights of corresponding prominences photographed in the K line. The mean heights were 58″·8 in K, 56″·1 in *H*-alpha, 53″·7 in $D_3$ and 50″·0 in *H*-beta.

Particulars of Doppler displacements in prominences and *H*-alpha dark markings observed with the spectrohelioscope are given below :—

| | Displacements towards Red | Violet | Both ways | Total |
|---|---|---|---|---|
| Prominences | 9 | 7 | 24 | 40 |
| *Hα* dark markings | 6 | 10 | 11 | 27 |

The mean daily area of *H*-alpha absorption markings (without applying foreshortening correction) was 3224 millionths of the Sun's visible hemisphere, representing a decrease of 28 per cent as compared with the previous year. The distribution in latitude shows peaks of activity at N. 25°–35° and S. 20°–30°, indicating a poleward drift of the zones of maximum activity by 5° compared with the previous year.

A. K. DAS.

## DOUBLE STARS

*New pairs.*—Wilson (*A.J.*, **55,** 153) gives a list of new pairs found with the interferometer, and van de Kamp (*A.J.*, **55,** 160) announces the duplicity of the proper motion star Ross 79.

*Measures.*—Measures of double stars are given by Armellini (*Contr. Mt. Mario*, No. 152), Camichel (*J.O.*, **32,** 94), Jonckheere (*J.O.*, **32,** 81), Muller (*J.O.*, **32,** 77; also photometric), van den Bos (*U.O.C.*, **5,** 312 and 371) and Wilson (*A.J.*, **55,** 153).

*Orbits*:

| Double Star | *P* | *e* | *a* | Computer | Reference |
|---|---|---|---|---|---|
| | | | ″ | | |
| ADS 588 | 296·05 | 0·39 | 1·37 | Rabe | *A.N.*, **276,** 262 |
| ,, 746 | 204·54 | 0·06 | 0·61 | Rabe | *A.N.*, **276,** 262 |
| ,, 940 | 165·9 | 0·37 | 0·418 | Rabe | *A.N.*, **276,** 262 |
| ,, 1158 | 63·8 | 0·86 | 0·311 | van den Bos | *U.O.C.*, **5,** 366 |
| ,, 1631 | 310·0 | 0·64 | 1·19 | Vidal | *Rev. Geof.*, **4,** 490 |
| ,, 2446 | 118·19 | 0·76 | 0·57 | Rabe | *A.N.*, **276,** 262 |
| ,, 3093 | 252·19 | 0·4156 | 6·865 | Artukhina | *A.J. Sov. Un.*, **25,** 180 |
| ,, 5234 | 116·13 | 0·72 | 0·857 | Rabe | *A.N.*, **276,** 262 |
| ,, 6483 | 57·04 | 0·77 | 0·440 | van den Bos | *U.O.C.*, **5,** 310 |
| ,, 6871 | 498·66 | 0·512 | 1·476 | Dommanget | *B.A.B.*, **4,** 30 |
| ,, 6871 | 125·6 | 0·45 | 0·64 | Vidal | *Pbl. Santiago*, **7,** 2 |
| ,, 7203 | 453 | 0·7 | 3·2 | Pensado | *Rev. Geof.*, **4,** 76 |
| ,, 7390 | 124·86 | 0·587 | 0·818 | Scuor | *Pbl. Trieste*, 229 |
| ,, 7871 | 144·74 | 0·659 | 0·620 | Giannuzzi | *Contr. Mt. Mario*, 154 |
| ,, 7871 | 213·02 | 0·08 | 0·578 | Rabe | *A.N.*, **276,** 262 |
| ,, 8630 | 171·764 | 0·8773 | 3·6483 | Wolf | *A.N.*, **277,** 75 |
| | 171·846 | 0·8794 | 3·7206 | | |
| ,, 8635 | 72·0 | 0·143 | 0·456 | Baize | *J.O.*, **32,** 49 |
| ,, 8804 | 25·87 | 0·500 | 0·662 | Haffner | *A.N.*, **276,** 145 |
| ,, 8804 | 25·83 | 0·494 | 0·672 | Pavel | *A.N.* **277,** 153 |
| ,, 8862 | 49·0 | 0·14 | 1·40 | Baize | *J.O.*, **32,** 49 |
| ,, 9301 | 30·00 | 0·150 | 0·210 | van den Bos | *U.O.C.*, **5,** 310 |
| ,, 10157 | 34·385 | 0·470 | 1·369 | Baize | *J.O.*, **32,** 49 |
| ,, 10374 | 80·0 | 0·90 | 1·05 | Baize | *l'Ast.*, **64,** 169 |
| ,, 11077 | 56·75 | 0·78 | 1·15 | Cid | *Urania*, 219 |
| ,, 11468 | 184·6 | 0·40 | 0·255 | Wilson | *A.J.*, **55,** 159 |
| ,, 12889 | 242·3 | 0·783 | 2·21 | Cester | *Pbl. Trieste*, 227 |
| ,, 12972 | 157·21 | 0·08 | 0·607 | Rabe | *A.N.*, **276,** 262 |
| ,, 14296 | 391·30 | 0·45 | 0·777 | Rabe | *A.N.*, **276,** 262 |
| ,, 14338 | 87·8 | 0·39 | 0·60 | Jonckheere | *J.O.*, **32,** 83 |
| ,, 14787 | 49·80 | 0·24 | 0·93 | Cid | *Urania*, 219 |
| ,, 16538 | 118 | 0·77 | 0·95 | Vidal | *Rev. Geof.*, **4,** 490 |
| (pos. 1900) | | | | | |
| $8^h\ 22^m{\cdot}0$ −48° | 27·7 | 0·18 | 0·267 | van den Bos | *U.O.C.*, **5,** 366 |
| $10^h\ 33^m{\cdot}1$ −47° | 16·0 | 0·70 | 0·316 | van den Bos | *U.O.C.*, **5,** 367 |
| $11^h\ 16^m{\cdot}4$ −53° | 42·77 | 0·74 | 0·275 | van den Bos | *U.O.C.*, **5,** 368 |
| $13^h\ 11^m{\cdot}3$ −34° | 66·7 | 0·05 | 0·270 | van den Bos | *U.O.C.*, **5,** 368 |
| $14^h\ 40^m{\cdot}5$ −20° | 111·4 | 0·66 | 0·6438 | van den Bos | *U.O.C.*, **5,** 369 |
| $16^h\ 50^m{\cdot}1$ − 8° | 1·655 | 0 | 0·185 | Baize | *J.O.*, **32,** 49 |
| $16^h\ 52^m{\cdot}1$ −37° | 31·16 | 0·230 | 0·169 | van den Bos | *U.O.C.*, **5,** 369 |
| $18^h\ 03^m{\cdot}2$ −22° | 9·48 | 0·40 | 0·168 | van den Bos | *U.O.C.*, **5,** 370 |
| $21^h\ 39^m{\cdot}5$ −58° | 6·32 | 0·66 | 0·2335 | van den Bos | *U.O.C.*, **5,** 370 |
| $22^h\ 52^m{\cdot}8$ −46° | 31·70 | 0·69 | 0·3094 | van den Bos | *U.O.C.*, **5,** 371 |

Baize (*J.O.*, **33**, 1) has published his second orbit catalogue. Aller (*Urania*, 219), Belorizky (*J.O.*, **33**, 49; *M.N.*, **109**, 596), Dommanget (*B.A.B.*, **4**, 28), Harting (*A.N.*, **278**, 264), Kulikovsky (*A.J. Sov. Un.*, **26**, 249), Pavel (*A.N.*, **277**, 153) and Wolf (*A.N.*, **277**, 75) discuss methods of orbit determination. Ishida (*Jap. J.A.*, **1**, 73) writes on the stellar problem of three bodies, with application to $\zeta$ Cancri.

*Miscellaneous.*—Ali (*A.J.*, **55**, 208) gives a note on ADS 14266, Baize (*J.O.*, **32**, 97) a comparison of distance measures with filar and non-filar micrometers, Bonnet (*Obs. Paris*) addenda to her earlier memoir on spectra, periods and eccentricities of binaries, Finsen (*M.N.A.S., South Africa*, **9**, 88) a note on an eyepiece interferometer. Jonckheere (*J.O.*, **33**, 57) writes about a micrometer with oblique wires and (*Obs.*, **70**, 187) a plea for the faint double stars, Kienle (*Sitz. Deut. Akad. Wiss. Berlin, Math.-Naturwiss. Kl.*, 1948, No. VI) about photometry of double stars. Martin (*Pbl. Trieste*, 231) has a note on Kuiper's close pair at $17^h\ 09^m{\cdot}2$, $+45°$, Muller (*J.O.*, **32**, 114) gives new fundamental distances of double stars and (*Ann. Strasb.*, **5**, 3) photometric observations of double stars. He has also published his doctor's thesis (*Fac. Sc. Univ. Paris*, 1948) on a new double-image micrometer.

Schmidt (*A.J. Sov. Un.*, **25**, 184) discusses the orbit planes of visual binaries, Sobolev (*id.*, 189) the same subject, Struve (*Sky & Tel.*, **9**, 186 and 216) visual double stars and Wolf (*A.N.*, **277**, 172) systematic errors in distance measurements.

W. H. VAN DEN BOS.

## COMETS (1950)

Only one new comet was discovered in 1950, although altogether thirteen were under observation at some time during the year. Of the twelve others, four were periodic comets whose returns had been predicted, and the remaining eight were comets followed from the previous years and included the two "annual" comets.

Of these last two, the periodic comet Schwassmann-Wachmann (1) was recorded by K. Reinmuth on minor planet plates taken with the 16-inch lenses of the Bruce telescope at Königstuhl on January 24 and 25; and the images were described by him as of a very faint diffuse disk, 30″ in diameter with no nucleus, the magnitude estimated as 16. This contrasts with H. M. Jeffers' description of his January 26 observation with the Crossley reflector at the Lick Observatory: magnitude 18·5, stellar nucleus with very faint coma. Further observations, by G. van Biesbroeck at Yerkes and Jeffers at Lick, continued from March till June, during which time the comet remained a nearly stellar object of around magnitude $18\frac{1}{2}$.

The same two observers, and Miss L. Oterma herself at Turku, also recorded the Oterma comet between February and April. It was at around its normal brightness, $15^m$, and it appeared as a rather condensed coma of about 7″ from which, on February 8, Jeffers noted a faint tail 1′·2 long westward. Both these comets were being followed again at the end of the year.

1948 h Wirtanen was under observation in January, and appeared somewhat brighter than expected: $13\frac{1}{2}^m$ (Johnson). It was followed during the Spring and recorded again, at about nineteenth magnitude (nucleus), in November and December by Leland E. Cunningham using the 60-inch reflector at Mount Wilson.

1949 a Johnson, which only came to perihelion in January, was at that time a diffuse object, 1′ in diameter, of magnitude around 12·1. It reached maximum, only slightly brighter, in March ($12^m{\cdot}0$, Boyer). Max Beyer, observing it visually with the 10-inch refractor at Bergedorf on March 10, described it as having a pointed coma about 2′ long, with a $13^m{\cdot}7$ stellar nucleus at the point, and the coma broadening to 1′ and continuing into a faint tail 6′ long in position angle 167°. The comet was followed till May, when it was about thirteenth magnitude, and then was recorded again by Cunningham at about seventeenth magnitude in November and December. It was still under observation in the new year by Van Biesbroeck with the 82-inch reflector ($f/3{\cdot}9$) at the McDonald Observatory.

1949 c Bappu-Bok-Newkirk, at the beginning of the year under review, was still nearly of the twelfth magnitude. It faded gradually, the coma, a well-condensed object of $2\frac{1}{2}'$ diameter, gradually becoming smaller, more diffuse, and fainter; and in March it showed a sharp nucleus of about fifteenth magnitude (Beyer, Jeffers). It was followed till May, when it was of the seventeenth magnitude (Jeffers); and it was recorded again, at about eighteenth magnitude (nucleus), in November and December by Cunningham at Mount Wilson.

The dates of the last known observations in 1950 of these and of other previous comets, are given in Table I. Some of them were still being observed early in 1951—see p. 240.

TABLE I

*Last known Observations of Previous Year's Comets*

| Comet | | Date | Mag.* | Observer | Remarks |
|---|---|---|---|---|---|
| | | 1950 | | | |
| 1925 II† | P/Schwassm.–Wachm.(1) | Dec. 16 | $19_n$ | Cunningham | |
| 1942 VII | P/Oterma | Dec. 16 | $18_n$ | ,, | |
| 1948 d | Pajdušáková–Mrkos | Feb. 9 | 19·2 | Jeffers | Faint coma 3″ or 4″ |
| 1948 h | Wirtanen | Dec. 16 | $19_n$ | Cunningham | |
| 1948 k | Wirtanen | Sept. 11 | $18_n$ | ,, | |
| 1949 a | Johnson | Dec. 13 | $17_n$ | ,, | |
| 1949 c | Bappu–Bok–Newkirk | Dec. 16 | $18_n$ | ,, | |
| 1949 h | P/Väisälä | June 18 | $19_n$ | ,, | |

* Subscript *n* denotes the magnitude is for the nucleus.

† Following the original designation usually used for it—revised is 1925 III.

Unsuccessful attempts to follow other comets of the previous year have been reported, and it is especially disappointing, from the point of view of the orbit computer, that no further observations of the periodic comet Shajn-Schaldach (1949 e) were obtained this year. The failure is curious since the comet was still not badly placed for observation in January and February, and normally

should not have been too faint for observation then. The December (1949) observations, however, gave some indications that abnormal fading may have set in, since the brightness then, around $14^m$, was a magnitude fainter than expected, despite the fact that the comet was at perihelion (December 7; $q=2{\cdot}3$) and such small changes in heliocentric distance as had taken place since October had been to lessen the distance.

The first comet of the year, 1950 a, was the periodic comet d'Arrest. Spurious images led to its recovery being erroneously reported in April, but G. van Biesbroeck did in fact find it with the 82-inch reflector ($f/3{\cdot}9$) at the McDonald Observatory on May 13·4, close to the positions predicted by A. W. Recht and by W. E. Beart. The image of it appeared as a fuzzy coma, 15″ in diameter and only slightly condensed, magnitude 16. He was then also able to locate the image of it on a plate taken on April 20·5 when it was $18^m$. It brightened gradually, reaching $11^m$ in July when it appeared as a diffuse coma, 3′ in diameter and but little condensed, containing a well-defined nucleus of magnitude $13\frac{1}{2}$ (Van Biesbroeck, Jeffers, A. Jones). It remained slightly brighter than twelfth magnitude, and of the same appearance, until mid-September, after which it faded gradually but was still under observation in the new year at about eighteenth magnitude.

1950 b, the only new comet of the year, was found by Rudolph Minkowski, in Ophiuchus on May 19·4, on plates taken for the Sky Survey with the 48-inch Schmidt telescope ($f/2{\cdot}5$) on Palomar Mountain. The coma, about 25″ in diameter, showed considerable central condensation, and a tail about 50″ long could be traced in position angle about 90°. The total brightness was about $11^m$—the original estimate of $8^m$ was almost certainly too bright. The comet brightened slightly, reaching $10^m$ in July, at which time the coma was 2′ in diameter, and had a bright central condensation containing a sensibly stellar nucleus of about thirteenth magnitude; and a faint tail could be traced for about 3′ or 4′ towards the E.S.E. Thereafter it faded slowly to about twelfth magnitude in September, and was not observed any more after October 10 till it had passed behind the Sun. It was seen again on December 17 by Van Biesbroeck, and was under observation in the new year, again reaching the tenth magnitude and continuing to brighten as it approached perihelion and its distance from the Earth decreased.

1950 c was the periodic comet Wolf (1), detected by Leland E. Cunningham, close to the positions predicted by M. Kamienski and by C. Dinwoodie, on four plates taken with the 60-inch reflector ($f/5$) at Mount Wilson on July 20–22; and subsequently it was also found on four plates taken on June 18–19. The images were essentially stellar, and the brightness on July 22 was found by direct comparison with the North Polar Sequence to be $18^m{\cdot}8$. It remained about eighteenth magnitude for the rest of the year, appearing in October "like an ill-defined star" (Van Biesbroeck); and it was still under observation at the end of the year.

1950 d was Daniel's periodic comet, recovered, close to the position predicted by F. R. Cripps, by L. E. Cunningham with the 60-inch reflector on August 16·5; and independently also by Van Biesbroeck with the 24-inch reflector at Yerkes Observatory on August 23 and by Antonín Mrkos with the 24-inch Zeiss reflector at the Skalnaté Pleso Observatory on August 24. The images showed

it as a somewhat condensed nebulosity about 25″ in diameter, and of seventeenth magnitude. It brightened to fifteenth magnitude in September (Jeffers) before fading again; and was still under observation in the new year.

1950 e, the last of the year, was Encke's periodic comet, the recovery of which by L. E. Cunningham with the 60-inch reflector at Mount Wilson took place at an exceptionally early date. On previous returns it has never been found till within about three months of perihelion passage. On this occasion it was actually recorded nearly eight months before perihelion, on July 21, while still in the outer half of its orbit and as faint as twenty-first magnitude! The identification however was not made until after the comet had been found on the plates of August 16, when it was of twentieth magnitude. All images were entirely stellar, and were found close to the position predicted by R. Luss—the prediction by the late L. L. Matkiewicz of Leningrad was later found to be even closer (in $T$). The comet brightened but slowly during the remaining months of the year, being still barely seventeenth magnitude in November; but by then a diffuse coma, at least 1′ in diameter, had become apparent (Van Biesbroeck), which in December showed a stellar nucleus of eighteenth magnitude (Cunningham).

Diffuse images of the eighth magnitude on single plates, taken on the borders of Cetus and Pisces on November 8 and 27, were reported by Akbar Ali from the Nizamiah Observatory at Hyderabad. Numerous searches failed to find any cometary object in the area, and there seems little doubt the images were spurious.

During this year unsuccessful searches were made for two comets not seen for many years.* During September and October, D. Martinoff, at the Engelhardt Observatory, Kasan, tried with a 15-inch Schmidt camera ($f/2{\cdot}4$) to locate Holmes's periodic comet, not seen since 1906, within an area of several degrees covering the prediction made by J. F. Polak. The other search made, also by Soviet observers, and by Van Biesbroeck on December 1, was for the periodic comet Tempel-Swift, not seen since 1908, in the positions predicted by S. Kanda (Tokyo).

The comets reported to be still under observation early in the new year (1951) were:

| | | | |
|---|---|---|---|
| 1948 h | Wirtanen | 1950 c | P/Wolf (1) |
| 1949 a | Johnson | 1950 d | P/Daniel |
| 1949 c | Bappu-Bok-Newkirk | 1950 e | P/Encke |
| 1950 a | P/d'Arrest | 1925 II | P/Schwass.-Wach. (1) |
| 1950 b | Minkowski | 1942 VII | P/Oterma |

Table II, giving the elements of cometary orbits, is arranged as in previous reports: the comets are listed in order of perihelion date; the symbol P/ indicates a periodic comet, and $p$ after the perihelion date that the elements were predicted ones.† The perihelion date, deduced from observations, when not given in a set of elements in the table, will be found in the notes appended.

* The references for these predictions are given on pp. 243, 244.

† The orbits by Soviet computers have been communicated by Professors A. Dubiago and M. Subbotin, through the Astronomical Council of the Academy of Sciences, U.S.S.R.

REFERENCES AND NOTES TO TABLE OF ELEMENTS

1889 V P/Brooks (2). (1) A. Dubiago, *Pub. Kazan Univ. Obs.*, **31**, 1950. Definitive elements derived from the investigation of the orbit over eight apparitions, 1889–1946, see note p. 243. Osc. epoch 1889 October 8·5 Berlin M.T.

1896 VI P/Brooks (2). (2) A. Dubiago, see ref. (1) above. Osc. epoch 1896 October 11·5 Berlin M.T.

1903 V P/Brooks (2). (3) A. Dubiago, see ref. (1) above. Osc. epoch 1903 November 25·5 Berlin M.T.

1911 I P/Brooks (2). (4) A. Dubiago, see ref. (1) above. Osc. epoch 1911 January 7·0 Berlin M.T. The Lick Observatory observation 1910 September 28 was the only one at this apparition.

1925 VII Shajn-Comas Solá. (5) V. V. Sakk and D. K. Kulikov, *Bull. Inst. Theor. Astron.* (Leningrad), **4**, No. 9 (62), 1951. Definitive elements from 215 observations covering $712^d$, 1925–1927. Osc. epoch 1925 March 1·0 U.T.

1925 X P/Brooks (2). (6) A. Dubiago, see ref. (1) above. Osc. epoch 1925 November 9·0 U.T.

1927 III P/Comas Solá. (7) Julie M. Vinter Hansen, *Pub. Copenhagen Obs.*, No. 154, 1951. Preliminary orbit, linked to apparitions in 1935 and 1944, including perturbations (Mercury to Pluto) by Cowell's method, as basis for her definitive investigation. Osc. epoch 1926 November 30·0 U.T.

1932 VIII P/Brooks (2). (8) A. Dubiago, see ref. (1) above. Osc. epoch 1932 October 3·0 U.T.

1932 IX P/Faye. (9) V. F. Zheverzheyev, MS. (*Inst. Theor. Astron.*, Leningrad). Preliminary elements from combined apparitions 1932 and 1940, including perturbations (Mercury to Neptune) ; as basis for definitive investigation of the motion of the comet 1925–1948. Osc. epoch 1932 November 9·0 U.T.

1939 VII P/Brooks (2). (10) A. Dubiago, see ref. (1) above. Osc. epoch 1939 September 24·0 U.T.

1940 II P/Faye. (11) V. F. Zheverzheyev, MS., see ref. (9) above. Osc. epoch 1939 November 3·0 U.T.

1941 VII P/du Toit-Neujmin-Delporte. (12) Miss N. F. Boeva, *Bull. Inst. Theor. Astron.* (Leningrad), **5**, No. 1, (64), 1951. Definitive, by correction of the orbit by P. Naur (*Pub. Copenhagen Obs.*, No. 141, 1945, see *M.N.*, **107**, 110, 1947, ref. 36) using about 100 observations, nearly double the number used by Naur, covering $91^d$. Osc. epoch 1941 August 24·0 U.T. The period is 7·3 days longer than Naur's value. A prediction for 1952 has been computed by the Cowell method.

1943 IV P/Daniel. (13) G. Merton, *Handbook B.A.A.* 1950, 45. Dubiago's elements (see *M.N.*, **107**, 110, 1947 ; ref. 48) but with $a=3{\cdot}589154$ to take account of mean motion linked to 1937 apparition, and $e=0{\cdot}574673$ to give same $q$ ; as used by F. R. Cripps for the 1950 prediction, see ref (21) below.

1946 e P/Brooks (2). (14) A. Dubiago, see ref. (1) above. Osc. epoch 1946 August 28·0 U.T.

1947 n Southern Comet. (15) G. Guigay, *J. des O.*, **33**, No. 5, 71, 1950. By differential correction of Schmitt's elements (see *M.N.*, **108**, 301, 1948 ; ref. 16) using 29 observations covering $36^d$. $q=0{\cdot}1100707$. The excess of eccentricity over unity has no significance, being about a quarter of the probable error of the determination, $\pm 0{\cdot}000120$.

1949 d P/Johnson. (16) Leland E. Cunningham, *H.A.C.*, 1100. From 11 observations covering $96^d$.

1949 e P/Shajn-Schaldach. (17) A. Dubiago, *Astron. Circ.* (U.S.S.R.), No. 93, 1949. An improved orbit from 10 observations covering $82^d$. Osc. epoch 1949 September 1·0 U.T.

1949 a Johnson. (18) Leland E. Cunningham, *H.A.C.*, 1087 ; *U.A.I.C.*, 1282. From selected observations covering $273^d$.

1950 a P/d'Arrest. (19) Albert W. Recht, *Handbook B.A.A.*, 1950, 40. Prediction from his 1943 elements (see *M.N.*, **107**, 110, 1947 ; ref. 47) with correction $-1{\cdot}2$ days to $T$, including perturbations (Mercury to Neptune) by Cowell's method. Osc. epoch 1950 June 8·0 U.T. Observation indicated $T$ 1950 June 6·395 U.T. (Cunningham, *H.A.C.*, 1101). See also note on prediction : *Ap. J.*, **55**, 79, 1950.

TABLE II. *The Elements*

| Comet | | *T* G.M.T. before 1925·0 U.T. from 1925·0 | *q* | *e* |
|---|---|---|---|---|
| 1889 V | P/Brooks (2) | 1889 Sept. 30·3469 | 1·950012 | 0·470812 |
| 1896 VI | P/Brooks (2) | 1896 Nov. 4·1353 | 1·959219 | 0·469461 |
| 1903 V | P/Brooks (2) | 1903 Dec. 6·2461 | 1·958905 | 0·469757 |
| 1911 I | P/Brooks (2) | 1911 Jan. 8·1300 | 1·963070 | 0·468835 |
| 1925 VII | Shajn-Comas Solá | 1925 Sept. 6·9785 | 4·180690 | 1·001941 |
| 1925 X | P/Brooks (2) | 1925 Nov. 1·8160 | 1·861650 | 0·487306 |
| 1927 III | P/Comas Solá | 1927 Mar. 22·1930 | 1·772492 | 0·574960 |
| 1932 VIII | P/Brooks (2) | 1932 Oct. 9·5299 | 1·869997 | 0·486095 |
| 1932 IX | P/Faye | 1932 Dec. 6·2305 | 1·619992 | 0·570415 |
| 1939 VII | P/Brooks (2) | 1939 Sept. 15·4214 | 1·871482 | 0·486051 |
| 1940 II | P/Faye | 1940 Apr. 24·9428 | 1·653784 | 0·565212 |
| 1941 VII | P/du Toit-Neujm.-D. | 1941 July 21·2136 | 1·305019 | 0·583105 |
| 1943 IV | P/Daniel | 1943 Nov. 22·5086 | 1·526564 | 0·574673 |
| 1946 e | P/Brooks (2) | 1946 Aug. 25·7974 | 1·878783 | 0·484641 |
| 1947 n | Southern Comet | 1947 Dec. 2·5873 | 0·110071 | 1·000032 |
| 1949 d | P/Johnson | 1949 Sept. 16·1947 | 2·248002 | 0·377008 |
| 1949 e | P/Shajn-Schaldach | 1949 Nov. 26·7284 | 2·234147 | 0·404828 |
| 1949 a | Johnson | 1950 Jan. 19·3173 | 2·553225 | 1·000671 |
| 1950 a | P/d'Arrest | 1950 June 6·595*p* | 1·377873 | 0·612275 |
| (1942 VII) | P/Oterma | 1950 July 15·6522 | 3·405513 | 0·142657 |
| 1950 d | P/Daniel | 1950 Aug. 24·310*p* | 1·464962 | 0·586267 |
| 1950 c | P/Wolf (1) | 1950 Oct. 23·750*p* | 2·497530 | 0·396399 |
| | | 1950 Oct. 23·629*p* | 2·497551 | 0·396381 |
| 1950 b | Minkowski | 1951 Jan. 15·2579 | 2·570303 | 1·0 |
| 1950 e | P/Encke | 1951 Mar. 16·118*p* | 0·338492 | 0·847232 |
| | | 1951 Mar. 15·787*p* | 0·338107 | 0·847370 |

(1942 VII) P/Oterma. (20) Miss L. Oterma, *U.A.I.C.*, 1292. Elements from observations covering 169$^d$, 1949 October to 1950 April only ; planetary perturbations included. Osc. epoch 1950 February 19·0 U.T.

1950 d P/Daniel. (21) F. R. Cripps, *Handbook B.A.A.*, 1950, 45. Prediction, including planetary perturbations, from elements given under ref. (13) above. Osc. epoch 1950 August 27·0 U.T. Observation indicated *T* 1950 August 23·85 U.T.

1950 c P/Wolf (1). (22) Cameron Dinwoodie, *Handbook B.A.A.*, 1950, 46. Prediction, including perturbations by Jupiter and Saturn, from preliminary elements by Kamienski for 1942. Osc. epoch 1950 October 6·0 U.T. (23) M. Kamienski, MS. Revised prediction using definitive perturbations 1942–1950. This is his definitive system Q5, continuing his previous accurate investigations of the motion since 1884. Osc. epoch 1950 October 6·0 U.T. Observation indicated *T* 1950 October 23·648 U.T.

1950 b Minkowski. (24) Jorge Bobone, *U.A.I.C.*, 1288. Representing 13 observations covering 70$^d$.

1950 e P/Encke. (25) L. L. Matkiewicz, *Astron. Circ.* (U.S.S.R.), No. 89, 1949. Prediction resulting from the continuation of his previous accurate work on the orbit, 1934–1947. Osc. epoch 1951 January 19·0 U.T. Observations near perihelion indicated *T* 1951 March 16·20 U.T., but residuals exceeding 1′ remain. (26) R. Luss, *Handbook B.A.A.*, 1950. Prediction based on G. Merton's elements for 1947 (*M.N.*, **108**, 128, ref. 15, 1948). Osc. epoch 1951 March 16. Observations near perihelion indicated *T* 1951 March 16·198 U.T., using corrected $a = 2{\cdot}215716$.

*of Cometary Orbits*

| Period (years) | $\omega$ | $\Omega$ | $i$ | Equinox | Computer | Ref. | Comet |
|---|---|---|---|---|---|---|---|
| | ° | ° | ° | | | | |
| 7·07 | 343·6044 | 17·9840 | 6·0685 | 1890·0 | Dubiago | 1 | 1889 V |
| 7·10 | 343·7958 | 18·0690 | 6·0594 | 1900·0 | Dubiago | 2 | 1896 VI |
| 7·10 | 343·6213 | 18·0593 | 6·0618 | 1900·0 | Dubiago | 3 | 1903 V |
| 7·10 | 343·4962 | 18·2152 | 6·0589 | 1910·0 | Dubiago | 4 | 1911 I |
| ... | 205·7619 | 357·4898 | 146·6997 | 1925·0 | Sakk, Kulikov | 5 | 1925 VII |
| 6·92 | 195·7067 | 177·4195 | 5·5532 | 1925·0 | Dubiago | 6 | 1925 X |
| 8·52 | 38·4788 | 65·9308 | 13·7632 | 1950·0 | Vinter Hansen | 7 | 1927 III |
| 6·94 | 195·8351 | 177·6805 | 5·5483 | 1925·0 | Dubiago | 8 | 1932 VIII |
| 7·32 | 200·0651 | 206·4667 | 10·5807 | 1950·0 | Zheverzheyev | 9 | 1932 IX |
| 6·95 | 195·6876 | 177·7034 | 5·5459 | 1950·0 | Dubiago | 10 | 1939 VII |
| 7·42 | 200·5336 | 206·3710 | 10·5514 | 1950·0 | Zheverzheyev | 11 | 1940 II |
| 5·54 | 69·3378 | 229·6075 | 3·2606 | 1950·0 | Boeva | 12 | 1941 VII |
| 6·80 | 6·1035 | 70·4328 | 19·8461 | 1950·0 | (Merton) | 13 | 1943 IV |
| 6·96 | 195·6053 | 177·6985 | 5·5398 | 1950·0 | Dubiago | 14 | 1946 e |
| ... | 196·2059 | 336·6043 | 138·5129 | 1950·0 | Guigay | 15 | 1947 n |
| 6·85 | 206·0171 | 118·1796 | 13·8753 | 1949·0 | Cunningham | 16 | 1949 d |
| 7·27 | 215·2348 | 167·3803 | 6·1538 | 1949·0 | Dubiago | 17 | 1949 e |
| ... | 40·0973 | 221·6317 | 131·3542 | 1950·0 | Cunningham | 18 | 1949 a |
| 6·70 | 174·4318 | 143·6137 | 18·0545 | 1950·0 | Recht | 19 | 1950 a |
| 7·92 | 354·6534 | 155·1242 | 3·9889 | 1950·0 | Oterma | 20 | (1942 VII) |
| 6·66 | 7·2430 | 69·7359 | 19·7121 | 1950·0 | Cripps | 21 | 1950 d |
| 8·42 | 161·1456 | 203·8797 | 27·3149 | 1950·0 | Dinwoodie | 22 | 1950 c |
| 8·42 | 161·1456 | 203·8795 | 27·3163 | 1950·0 | Kamienski | 23 | 1950 c |
| ... | 192·5548 | 38·1962 | 144·1446 | 1950·0 | Bobone | 24 | 1950 b |
| 3·30 | 185·2034 | 334·6768 | 12·3740 | 1950·0 | Matkiewicz | 25 | 1950 e |
| 3·30 | 185·2172 | 334·7219 | 12·3802 | 1950·0 | Luss | 26 | 1950 e |

## Additional Notes

*Individual Comets*

1948 a Mrkos. The observation by B. Protitch on 1948 January 10, referred to in the Report for 1948 (*M.N.*, **109**, 249, 1949), was an independent discovery of this comet which, owing to bad weather, could not then be confirmed.

P/Brooks (2). A. Dubiago: "The motion of periodic Comet Brooks from 1883 to 1946", *Pub. Kazan Univ. Obs.*, **31**, 1950—the elements at the eight apparitions are given in the table above. He found a secular acceleration of the motion, decreasing before the close approach to Jupiter, 1922 January 12 (dist.=0·086 A.U.), and increasing afterwards; also a secular decrease in eccentricity. He traced the comet back past the extremely close approach to Jupiter, 1886 July 21 (dist.=0·00096 A.U. =2·02 equat. radii of Jupiter), to 1883, when he found the period had been 31·4 years, the perihelion distance 5·5 A.U. and the perihelion longitude 176° different!

P/Halley. M. Kamienski: "Researches on the Periodicity of Halley's Comet, Part I—Determination of the average Period of its Revolution", *Bull. Acad. Polonaise* (Cracovie), Série A, 1949, 101.

P/Holmes. J. F. Polak: "The Motion of Comet Holmes, 1925–1950", *A.J.* (U.S.S.R.), **26**, 156, 1949. He predicted the return for 1950, $T$=February 15·97 U.T. It will be recalled that F. Koebcke (Poznan) is investigating the orbit of this comet, see ref. *M.N.*, **109**, 256, 1949.

P/Kopff. F. Kepiński: "The Motion of the Periodic Comet 1906 IV (Kopff)", *Pub. Inst. Astron. pratique* (Varsovie), No. 26, 1950.

P/Reinmuth (1), 1949 f. An observation, recorded more than three weeks before the recovery by Mrkos, has been published by H. M. Jeffers: *L.O.B.*, No. 523, 1950.

P/Tempel-Swift. A prediction by S. Kanda for the return in 1950 is published in the *Japan Astronomical Study Association Circular*, No. 88, 1950 July 24. He gives $T=1950$ October 21·13 U.T.; but there is another prediction by him, in *Circular* 92, 1950 December 7, giving $T=1950$ September 30·10 U.T.

*General*

F. Baldet: "Liste Générale des Comètes de l'Origine à 1948", *Annuaire du Bureau des Longitudes pour l'an* 1950—also a separate reprint.

M. Beyer: "Physische Beobachtungen von Kometen", VII and VIII, *A.N.*, **278**, 217, 1950; **279**, 49, 1950. The latter, and a section of the former, contain analyses of the observations of a number of comets for correlations between variations of their brightness and solar activity.

J. Bouška: "Absolute Brightness of Comets 1946 d, 1947 c and 1948 l", *Bul. Astron. Institutes of Czechoslovakia*, **2**, No. 4, 60, 1950.

B. U. Levin: "On the Change in the Brightness of Comets in Relation to their Heliocentric Distances", *A. J.* (U.S.S.R.), **25**, No. 4, 246, 1948—see note in *Astron. News Letter* (U.S.A.), No. 39, 9, 1948 November. And see also previous paper *A.J.* (U.S.S.R.), **20**, 48, 1943.

J. H. Oort: "The Structure of the Clouds of Comets surrounding the Solar System, and a Hypothesis concerning its Origin", *B.A.N.*, **11**, No. 408, 91, 1950.

S. K. Vsessviatsky: "On the Origin of Comets", *A.J.* (U.S.S.R.), **25**, No. 4, 256, 1948—see note in *Astron. News Letter* (U.S.A.), No. 39, 5, 1948 November.

Fred. L. Whipple: "A Comet Model. Part I. The Acceleration of Comet Encke", *Ap. J.*, **111**, No. 2, 375, 1950; *Harvard Reprint* 337.

G. MERTON.

## ADDRESS

*Delivered by the President, Professor W. M. Smart, on the Award of the Gold Medal to Professor Antonie Pannekoek*

As announced at the January meeting of the Society, the Council has awarded the Gold Medal to Antonie Pannekoek for his work in astrophysics and on the structure of the galactic system. It is now my privilege to give a resumé of our Medallist's principal achievements during his long and active life.

It is not given to many to start an astronomical career at 16, even on an amateur basis; at this tender age our Medallist began his studies of the Galaxy, a subject which has engaged his attention almost right up to the present time. Of his other early activities mention should be made, in passing, of his photometric studies of the eclipsing binaries $\beta$ Lyrae and Algol (the latter the subject of his Leiden thesis in 1902) and of the light-curve of Polaris, confirming Hertzsprung's earlier discovery of the variability of this star.

In 1899 we find Dr Pannekoek at Leiden Observatory engaged mainly in meridian circle observations, and from 1906 to 1914 in Germany. During this latter period he became interested, through Kugler's works, in ancient astronomy, tangible results following in the form of two publications, one on Babylonian astronomy and the other on the origin of the Saros. During the same period he began his detailed investigation of stellar distribution and the structure of the galactic system, basing his work at first on counts of stars of given magnitudes taken from the available catalogues.

About this time Kapteyn had given a representation of the stellar distribution in the local system in terms of ellipsoids of revolution. In extending this work, dealing with the northern and southern galactic hemispheres separately, Dr Pannekoek paid greater attention to localized distributions and by separate treatment of stars of different spectral classes he showed that the local system was in effect an irregular agglomeration of star-clouds, amongst which the clouds of the B type stars were notably well defined.

In 1919 our Medallist began his association with the University of Amsterdam, and soon he had founded the Astronomical Institute of Amsterdam after the model of the Kapteyn Laboratory at Groningen; although the Institute was at first equipped with simpler forms of measuring instruments, it was only in 1927 that he acquired a microphotometer for the special photometric studies to be referred to later. The first two volumes of the Institute's publications were devoted to the galactic investigations already mentioned, the first volume including a fine set of density-charts; in the second volume a particularly interesting phenomenon was described, a mutual exclusion effect between the bright B and K type stars in clusters.

Later, a photometric survey of the northern Galaxy by means of extra-focal photography was completed in 1933, the plates being taken by Max Wolf at Heidelberg; the southern half of the Galaxy was similarly studied by means of plates taken at Lembang Observatory in Java; this latter work was published only so recently as 1949.

Our Medallist's astrophysical investigations began in 1922, and were to a great extent inspired by Saha's pioneer paper of the previous year. He first applied Saha's ionization formula to the conditions of radiative equilibrium

and investigated the heights of formation of the Fraunhofer lines in the solar atmosphere, later extending this work to the stars. In this work he emphasized the importance of the effect of surface gravity on the relative strengths of arc and spark lines, particularly with reference to the method of spectroscopic parallaxes.

In later investigations he introduced surface gravity as a physical parameter in preference to pressure, the latter being unsatisfactory as a characteristic of stellar atmospheres, owing to its immense variation with depth.

Then followed a period when he was engaged in an extensive programme of measuring relative line-intensities in a wide range of spectral types, using plates supplied by various observatories, including Victoria, at which he later spent six months securing, himself, further observational material. These long investigations contributed greatly to the clarification of the problem of spectral classification, especially as regards the differences between giants and dwarfs.

Meanwhile, theoretical researches continued to be prosecuted by Professor Pannekoek. Turning to the detailed structure of stellar atmospheres, he realized that the departure from thermodynamic equilibrium would have a considerable effect on ionization, and in 1926 he succeeded in establishing the appropriate correction to the Saha ionization formula. A member of the Dutch eclipse expedition to Lapland in 1927, he obtained new material, from observations of the flash spectrum, for investigating the heights and intensities of chromospheric lines, confirming Milne's view that the Fraunhofer lines are formed below the chromosphere.

Our Medallist next turned to the problem of line-profiles, developing his well-known numerical solutions of the equation of transfer for different models of stellar atmospheres. Later, he dealt theoretically with the central intensities of Fraunhofer lines, colour temperatures and the applications of limb-darkening.

In 1935, in collaboration with his pupil Vermeij, he published an important investigation on the Stark effect arising from the electric fields of electrons and ions. This work led him to realize that the disturbance of the highest Bohr orbits of the hydrogen atom by nearby charged particles would prevent quantization of the combined system, so merging the highest members of the Balmer series into the continuum. In a later paper he was the first to establish the relation, since confirmed experimentally, between the last visible member of the Balmer series and the electron and ion densities.

In 1942, Professor Pannekoek was dismissed from his University Chair by the Germans then in occupation of Holland. In the intervening years he has been active in completing several investigations—the latest on "Line-intensities in spectra of advanced type" in *Victoria Publications* (1950)—and in particular, he has been able to devote a considerable part of his enforced leisure to the continuation of his historical studies, the fruits of which are now in course of publication and which bear witness to his keen interest in the relations between science on the one hand and the varied human activities of past and modern society on the other.

To the distinguished role of Gold Medallists is now added the name of one whom the Society delights to honour for his many outstanding achievements. I am sure that the Fellows would like me to convey to Professor Pannekoek our sincere wishes for many fruitful years to come and to assure him of a very warm welcome when he comes in April to deliver the George Darwin Lecture and to receive the Gold Medal, our highest recognition of distinguished service to our science.

## ADDRESS

### *Delivered by the President, Professor W. M. Smart, on The First Half of the Twentieth Century: a Partial Review*

A few weeks ago we entered the second half of the twentieth century; the present occasion thus seems to be a suitable opportunity for reviewing some of the principal achievements in astronomy during the last fifty years, a period within the lifetime of some of us here today. Obviously it would be impossible within the time at my disposal—even if I were qualified in all departments of our rapidly expanding science—to cover more than a small portion of the immense field of observational and theoretical enquiries which have been pursued with almost unbelievable acceleration notably during the last decade or two. A hundred years ago it was still possible for a scientist—and, for that matter, a man devoted to the humanities—to be familiar with, and even an authority in, more than one of the recognized departments of knowledge. These days have gone, and the most that many of us (at least I speak for myself) can hope to achieve is a reasonably intimate acquaintance with one or two of the many sections into which a great science such as ours is now divided.

I think that there is a tendency at the present time to be too much absorbed by the many speculative aspects of astronomy, however fascinating these may be, and to neglect in our general conspectus much of the patient work in fundamental astronomy carried on quietly and almost unobtrusively in many of the observatories scattered over the globe and on which the whole structure of our contemporary knowledge is reared. Much of what I propose to discuss will be concerned with problems and investigations coming within the second category. It might have been anticipated in 1900 that these problems, many of them of an ancient vintage, would have been solved to our general satisfaction by this time; although it is true that a very high degree of observational accuracy has now been attained in many departments, yet this increased precision has frequently pointed the way to new difficulties of interpretation and suggested new problems for investigation.

At the beginning of the century there were serious misgivings as to the accuracy of the adopted value of the solar parallax, defining the astronomical unit of distance. The value of 10″, derived from diurnal observations of Mars first by Flamsteed, then by Bradley and Pound, and also, just about two centuries ago, from the comparison of observations of Mars made by Lacaille at the Cape of Good Hope with similar observations made at northern observatories, was the first relatively accurate determination of this fundamental constant. The two transits of Venus in 1761 and 1769 provided a variety of results lying between 8″·5 and 9″·5 according to the combination of observations made in different parts of the globe. This lack of precision from what appeared to be a perfect geometrical method arises, as we now know, from the effects of the atmosphere of Venus in rendering uncertain the observed times of ingress and egress of the planet on and from the solar disk. In the *Nautical Almanac* for 1801 the round figure of 9″ was used and this remained the official value for a third of a century, being replaced in 1834 by the value of 8″·5776 derived by

Encke from an elaborate discussion of the two eighteenth century transits. The implied accuracy of this last result is very impressive although, it need hardly be stated, entirely illusory. Encke's value, retained for a quarter of a century, was superseded in 1870 by an indirect determination derived by Le Verrier from the observed value of the parallactic inequality of the Moon; this is a perturbation in longitude, arising from the action of the Sun, with a period of a synodic month and an observed amplitude of about 125″. The theoretical expression for the amplitude involves the ratio of the semi-major axes of the lunar and solar orbits; the former being known, the solar parallax is then readily deduced. Le Verrier's value of 8″·95 remained the standard parallax until 1881. It may be interpolated here that a new determination of the lunar parallax made last year from photoelectric timings of the occultation of stars, each observed at a series of stations in the U.S.A., yields a result (regarded at the moment as preliminary) in terms of the lunar distance, showing an increase of 6 km. over the adopted value.

In 1882 the value of 8″·848 for the solar parallax was introduced; this was a weighted mean derived by Newcomb from a variety of determinations, including a re-discussion of the transit of Venus in 1769, observations of Mars in 1862, the parallactic inequality of the Moon, and the observed value of the constant of aberration in association with Foucault's measurement of the velocity of light : it is of interest to note that the last method gave 8″·860 for the solar parallax, a surprisingly accurate result in view of the difficult practical problem of measuring the velocity of light with the physical resources available at the time. Newcomb's value of the solar parallax survived till the end of the century.

Meanwhile astronomers had not been inactive in pursuing more direct investigations. Gill, in 1877, using a heliometer, the most accurate instrument for this kind of work at the time, and adopting the diurnal method, obtained the value of 8″·78 from a series of observations of Mars carried out on the Island of Ascension : this result, although apparently of high accuracy, suffered from the suspicion that the red colour of the planet introduced systematic effects arising from atmospherical dispersion. A few years later a more determined attack was made by Gill in collaboration with four northern observatories, the objects observed being the three minor planets Iris, Sappho and Victoria; the result was 8″·802. New determinations of the solar parallax from the constant of aberration and the parallactic inequality of the Moon were substantially in agreement; against these Newcomb had meanwhile produced two almost identical values, 8″·762 and 8″·759 derived from gravitational considerations. Although a conference of the superintendents of the four principal almanacs decided in favour of Gill's value of 8″·80 to be used as the official solar parallax from 1901 (a value which is still in use), Newcomb's prestige in the realm of celestial mechanics induced a feeling of incertitude in the adopted value which could only be allayed by a new concerted attack with all the increased resources rapidly becoming available.

The discovery of the minor planet Eros in 1898 occurred opportunely; its orbit was found to be greatly elongated so that at its nearest approach to the Earth it is distant only 14 million miles. The opposition of 1900–1 was seen to be eminently favourable and preparations were immediately set on foot to take advantage of this stroke of good fortune. In 1900, eighteen photographic

telescopes were in commission; although the photographic method had yet to prove itself in this exacting field of astrometry, it was nevertheless felt that the new technique would offer very distinct advantages over the visual methods hitherto employed. The reduction of the great mass of observations was entrusted to Hinks at Cambridge, and after about ten years of careful and exacting work the final result for the solar parallax was announced to be $8''{\cdot}806 \pm 0''{\cdot}004$, corresponding to a mean solar distance of 92,900,000 miles.

In addition to determining the solar parallax, the observations furnished material for ascertaining the mass of the Moon, or rather the ratio of the lunar and terrestrial masses. The motion of the Earth around the Sun is rather more complicated than that described simply as elliptic; it is the centre of mass of the Earth-Moon system that moves in this way. Accordingly, the observed positions of Eros include an effect, known as the lunar equation, which depends on the Earth's motion relative to the centre of mass and this involves the ratio of the masses of the Earth and Moon, as well as the solar and lunar parallaxes. The observations furnish the numerical value of the lunar equation; with the observed value of the solar parallax and the adopted value of the lunar parallax, the ratio of the masses is then calculated. Hinks found that this ratio $\mu$ (mass of Earth to mass of Moon) was $81{\cdot}53 \pm 0{\cdot}047$—a result evidently of considerable precision as judged by the probable error.

With $\mu$ known it is then possible, from the theory of precession and nutation and the observed value of the luni-solar precession, to deduce the constant of nutation and the mechanical ellipticity of the Earth (a relation between the moments of inertia about the principal axes of figure); the former was found to be $9''{\cdot}213$, in good agreement with the present observed value, and the latter 1/305.

A much more favourable opposition of Eros occurred thirty years later—the minimum geocentric distance of the planet on this occasion was about 16 million miles, just a little more than half that at the 1900 opposition. Telescopes of longer focal length were now available; photographic technique was greatly improved; further, it was realized that a similar opportunity would not occur for a long time. These were all irresistible arguments for undertaking what was hoped to be a final campaign for determining the solar parallax and for clearing up inconsistencies between observed and derived values of the associated constants. The scale of the operations, placed under the direction of Spencer Jones, is indicated by the fact that no fewer than thirty telescopes were engaged in the observational programme, contributing in all a total of 2847 plates.

When the reductions had been considerably advanced what seemed a fatal blow to the entire enterprise was delivered by Vick of Bergedorf in the suggestion that Eros was an unsuitable body for the determination of the solar parallax. Thirty years before, Hinks had some evidence that the brightness of Eros varied in a period of $2^{h}\,38^{m}$, the inference being that the planet was of irregular shape or of varying reflecting power over its surface; in either event the centre of the photographic image would not correspond to the centre of mass of the planet. It may be added that direct observation has recently shown that the former alternative is certainly true. Vick's suggestion, in greater detail, was to the effect that Eros was actually a complex system consisting of at least three discrete bodies and that consequently the positions of the composite images

would include unknown fluctuations of a magnitude not to be tolerated in a precise evaluation of the solar parallax. Happily, an exhaustive investigation of the observational material disposed of this suggested complication. Even now we can almost hear the sigh of relief with which the Astronomer Royal felt encouraged to complete the long investigation. The principal result was the value of $8''{\cdot}790 \pm 0''{\cdot}001$ for the solar parallax, corresponding to the Sun's mean geocentric distance of 93,005,000 miles. The lunar equation led to the value of 81·27 for $\mu$ (the ratio of the Earth's mass to the mass of the Moon). With these values and with the adopted value for the constant of precession, the nutation constant was found to be $9''{\cdot}227$, markedly in excess of the observed values which range closely round $9''{\cdot}210$; amongst these latter may be mentioned the value of $9''{\cdot}213$ derived from the Greenwich observations with the Cookson floating telescope in 1911–1931 and the Pulkova result of $9''{\cdot}211$ derived from 45,000 observations made between 1904 and 1941. If the calculations are reversed, with the constant of nutation assumed to have its observed value, the solar parallax comes out to be $8''{\cdot}841$, a wholly inadmissible value.

It is to be remarked that the theory of precession and nutation is built upon an important hypothesis which sometimes we are in danger of forgetting, namely, that of the perfect rigidity of the Earth; consequently, the *calculated* value of the nutation constant is intimately connected with this hypothesis. The departure from rigidity must evidently be small but it may just account for the lack of reconciliation between the derived and observed values of the nutation constant. In recent years, geophysical studies have begun to shed some light on the internal constitution of the Earth. If the Earth has a fluid core, then it is suggested by Jeffreys that the corrections due to non-rigidity will not have the same effect with respect to the nutation in longitude and to the nutation in the obliquity. It is evident that the task of the practical astronomer is certain to be more exacting than ever in this field if he is to contribute reliable information of the kind contemplated.

The first half of our century witnessed an outstanding event in the realm of celestial mechanics—the completion of E. W. Brown's lunar theory. From Newton onwards nearly every mathematical astronomer of note had made some definite contribution to the difficult problem of ascertaining the motion of the Moon with an accuracy commensurate with the increasing precision of observational technique. In 1900 the lunar tables used in the *Nautical Almanac* were those of Hansen, published as far back as 1857, and they remained in force until 1922. During the second decade the *Connaissance des Temps* used the tables, founded on Delaunay's theory, which were published under Radau's direction in 1911. Brown's monumental investigations, originally undertaken on the advice of Sir George Darwin, in honour of whom our Darwin Lectureship was instituted by Sir James Jeans, have their foundation on two remarkable papers by G. W. Hill in 1877, one entitled " Researches in the Lunar Theory " and the other " On the part of the Lunar Perigee which is a function of the mean motions of the Sun and Moon ". Hill's method involved the use of rectangular coordinates referred to axes moving in the ecliptic with the Sun's mean motion and had some points of affinity, in conception at least, with Euler's second lunar theory, based on axes moving in the ecliptic with the Moon's mean motion. Hill's papers were notable for new mathematical devices, particularly the introduction of infinite determinants for the first time into analysis. Hill's papers

may be said to have acted as a kind of signpost pointing the way towards a more perfect lunar theory than had yet been devised; but it required a master of consummate mathematical ability to devote his skill and energy to the long journey ahead. Brown attacked the problem in three stages. In the first—the classical problem of three point-masses—he completed the investigation of the Moon's motion under the perturbative action of the Sun. In the second he treated the actions of the planets arising directly in the usual way and indirectly through their effects on the orbital motion of the Sun. The third stage involved the numerical determination of the constants entering into the final solutions; then followed the computation of the tables, the work being frequently lightened by ingenious mathematical devices. The mathematical theory, published in instalments in our *Memoirs* beginning in 1897, was completed in 1908; the tables were published in 1919 and were first used in the *Nautical Almanac* for 1923. One particular result may be noted—the value of 5″·91 for the Moon's secular acceleration, with which Adams' value, obtained half a century before and about which there was a long and heated controversy, was in excellent agreement. The observed value of the acceleration is about twice that mentioned, the excess being attributed to the effect of the slowing-up of the Earth's rotation through tidal friction.

Brown's distinguished work received well-merited recognition by the award of our Gold Medal in 1907, the seventh award claimed by lunar theory. It needs no great power of divination on my part to suggest that the perfection of Brown's theory will be a stumbling-block to an award on similar grounds for many years to come.

The last fifty years have seen a large addition to the number of satellites, no fewer than nine having been discovered, if we include Phoebe (Saturn's ninth satellite) found by W. H. Pickering in 1898 although its precise status was only determined later. The most recent accessions are Miranda (Uranus V) and Nereid (Neptune II) both discovered at the new McDonald Observatory in 1948 and 1949 respectively. All of the new bodies are small, probably no more than two or three hundred miles in diameter. It is hardly likely that the known total of 30 satellites represents the entire number of these bodies and, if the new great telescopes are given the necessary opportunities, we can anticipate some further additions to the planetary families. A great deal of the interest in the new satellites arises from the large proportion of retrograde orbits which present a problem of great concern, as well as of difficulty, to the cosmogonist. Three of the new attendants of Jupiter, for example, move in retrograde orbits, a circumstance which shatters the conception held fifty years ago that the Jovian system was, in many respects, a replica on a small scale of the solar system itself. A feature of the retrograde satellites which is almost certainly of real significance in cosmogonic speculations is that in the Jovian and Saturnian systems these bodies are at very great distances from their primaries as compared with their orthodox brethren and consequently more susceptible to extraneous gravitational influences. I shall return to this point later.

At the beginning of the century the solar system was bounded by the orbit of Neptune. With the great increase in instrumental power it was not unnatural to speculate on the possibility of extending the planetary system by new discoveries. One of the principal functions which Lowell had postulated for his new observatory at Flagstaff was an organized search for an extra-neptunian

planet. To guide the search Lowell investigated, after the manner of Adams and Le Verrier, the discordances between the observed and predicted positions of Uranus, attributing these to the gravitational attraction of an exterior planet. It may be remarked firstly that Neptune was not considered in this connection as this planet had traversed no more than a third of its orbit since its discovery in 1846, and secondly that the discrepancies alluded to were but a small fraction of those at the disposal of Adams and Le Verrier, the largest residual in longitude being just about 2″. In 1915 Lowell completed his theoretical investigation, the main result of which was the specification of two possible and antipodal positions of the hypothetical planet. Then ensued several years of intense photographic observations, culminating in the discovery, by Tombaugh, of a new member of the solar system—later named Pluto—in January 1930, the official date of discovery being, however, deferred till March 13 so as to coincide with the date of Herschel's discovery of Uranus in 1781. The discovery naturally caused considerable interest and even amazement when it became known that the new planet was found within 6° of one of Lowell's predicted positions; it was at once inferred that the achievements of Adams and Le Verrier had been successfully repeated, despite the fact that the telescopic appearance of Pluto gave every indication that its mass was hardly likely to be sufficient to disturb the orbit of Uranus by observable amounts.

The question as to whether Lowell should or should not be acclaimed the theoretical discoverer of the new planet was quickly settled. In the first place, since the discordances between the observed and predicted positions of Uranus were as a rule no greater than the unavoidable errors of observation, it was highly improbable on general grounds that these residuals bore any real relationship to the perturbations arising from the action of Pluto, and when the discordances were examined more carefully they failed to reveal the characteristics of period normally associated with planetary perturbations. Complete support to this conclusion was furnished through E. W. Brown's application of a criterion to the residuals—based on a simple trigonometrical identity which had previously been suggested for the determination of hidden periodicities associated with a continuous series of observations. The result of this very thorough investigation left no doubt that the discovery of Pluto was entirely fortuitous, in the sense of being wholly unrelated to Lowell's mathematical investigation. It may be added that, by applying the criterion to the residuals as used by Adams and Le Verrier, Brown showed conclusively why their predictions were successful, despite the fact that the true elements of Neptune's orbit differed considerably—notably as regards the semi-major axis—from the predicted values.

A few months ago Kuiper, observing with the new 200-inch telescope on Mount Palomar, succeeded in measuring the angular diameter of Pluto; this proved to be no more than 0″·2, giving a linear diameter of 3600 miles. With any reasonable assumption as to density, the planet's mass is unlikely to exceed one-tenth that of the Earth, from which it may be firmly concluded that the new planet is incapable of producing observable effects on the orbit of Uranus.

Pluto's orbit proved to be greatly elongated—the eccentricity is about a quarter, the largest for the major planets—and inclined at an angle of about 17° to the ecliptic. At perihelion, the planet is approximately at the same distance from the Sun as Neptune, and this fact suggested to Lyttleton the possibility of a close encounter between the two planets when, as a result of

planetary perturbations over a long interval of time, the apse of Pluto's orbit will lie in or near the plane of Neptune's orbit. A close encounter, it is shown, cannot result in the ejection of Pluto from the solar family although, evidently, its orbit would be greatly altered. But when a close encounter with Triton (Neptune's retrograde satellite, with a mass equal to that estimated by Kuiper for Pluto) is considered, several interesting possibilities are envisaged, amongst which are the following: (i) Triton's orbit may be changed into a direct orbit by Pluto's influence, the latter body retaining its planetary character; (ii) Pluto may be captured in a direct orbit, Triton's orbit remaining retrograde; (iii) under exceptional circumstances Pluto may be captured by Neptune in a direct orbit, with the reversal of Triton's orbit from retrograde to direct; in this event, Neptune will possess two normal satellites revolving in direct orbits. The last process is clearly reversible in time so that in the far distant past it is possible that Neptune had two normal satellites and, through gravitational action between them, one had its motion reversed and the other was expelled from Neptune's control to acquire the status of an independent planet. As I have remarked earlier, the retrograde satellites present a difficult problem to the cosmogonist; but, at any rate, the investigation just described in outline does offer a suggestion as to one mechanism by which retrograde motions may be produced—with what degree of probability, however, it is impossible to estimate.

One of the interesting theoretical problems of celestial mechanics was that generally known by the name of "Lagrange's three particles". Lagrange's theorem can be briefly stated in the form which concerns us here, namely, that if three point-masses are placed at the vertices of an equilateral triangle and are projected with appropriate velocities, then they will continue to move under their mutual attractions so as to maintain the equilateral configuration. The question as to the stability of these motions was investigated in 1875 by Routh, who showed that for small displacements from the equilateral vertices the stability of the system was assured provided the masses satisfied a particular criterion. The study of this problem, originally an exercise in dynamical theory unrelated to the celestial scene, continued to be of theoretical interest only until the discovery, in 1906, of a minor planet subsequently named Achilles. The new body, whose longitude at the time of discovery was about 56° ahead of Jupiter, was shown by Berberich to be at a heliocentric mean distance almost exactly equal to that of Jupiter; also, the orbital eccentricity was large, of the order of one-seventh, so that its aphelion distance was about $\frac{3}{4}$ of an astronomical unit greater than the radius of the Jovian orbit. Charlier was the first to notice that the new planet, together with the Sun and Jupiter, provided an illustration in the heavens of the celebrated Lagrangian problem; further, the necessary criterion for stability, associated with small departures from the equilateral configuration, was easily satisfied. Altogether thirteen minor planets with mean distances approximately equal to that of Jupiter are known; twelve have now received the names of the principal protagonists in the Graeco-Trojan war described in the *Iliad*; of these, seven are approximately 60° ahead of Jupiter in longitude and five about 60° behind. It is perhaps unfortunate that the Trojans and the Greeks are not separated according to their relative Jovian longitudes; however, the general name of Trojans is applied to all these bodies without discrimination.

The dynamical theory of these small bodies is more difficult than usual owing to the near equality of their mean angular motions round the Sun. To a first approximation the principal oscillation of a Trojan relative to the appropriate equilateral vertex—known as the libration—has a period of about 146 years, its path relative to the vertex being an ellipse with its major axis perpendicular to the heliocentric radius vector of the vertex. Further, the amplitude of the libration is, for at least one of the Trojans, as much as 20°, so that the perturbed planet is only 40° from Jupiter in longitude at one extremity of the libration ellipse. The high eccentricities and inclinations to Jupiter's orbital plane—the latter as large as 20°—add still more analytical difficulties to a complete theory of the motions.

In normal planetary theory the developments are made, for successive approximations, according to powers of the mass $m$ of the disturbing planet; but in Trojan theory the developments have to be made according to $m^{1/2}$ (in this case Jupiter is the disturbing planet, its mass $m$ being $\frac{1}{1045}$ so that $m^{1/2}$ is about $\frac{1}{32}$). The most exhaustive investigations of the Trojans are those of E. W. Brown, which are built up on two assumptions; first, that the difference between the heliocentric longitudes of Jupiter and a Trojan is always strictly non-secular so that the motion in longitude is represented by oscillations about a point at or near the equilateral vertex; and, second, that the range of these oscillations at any time is not so large as to bring the Trojan within the predominant control of Jupiter, the Sun's attraction then playing only a subsidiary role. Brown's theory has been applied numerically by Brouwer and Eckert to the orbits of Achilles and Nestor respectively.

Any full-scale planetary theory is valid for only a limited time, past or future; in the case of the Trojan theory the limit of validity is very much smaller. Accordingly, the nature of the second assumption suggests some speculations as to the origin and eventual fate of the Trojans. If it should prove that their orbits are becoming more stable, it might appear that these bodies were formerly under the gravitational control of Jupiter, in other words, that they were members of the Jovian family of satellites. On the other hand, if the total effect of planetary perturbations, including those of Saturn in particular, is to reduce the minimum difference between the heliocentric longitudes of a Trojan and Jupiter, then we may contemplate for the far distant future an accession to Jupiter's number of satellites, with direct or retrograde motion according to circumstances. We may even take a further leap and suggest that the Jovian retrograde satellites known at present may be the result of this kind of gravitational interplay in the distant past.

Significant developments are now taking place in the field of planetary orbits with a view to the revision of the current theories which have their basis on the classical investigations of Newcomb in particular. For example, the theory of Neptune is known to be inexact principally because of errors in the adopted values of the elements, these errors arising from the insufficient arc of the planet's orbit that has so far come under observation. In addition, there are minor defects in the mathematical theories requiring clarification and, more important, accurate values for the planetary masses have become a prime necessity. A long-term programme has recently been undertaken by the U.S. Naval Observatory, Yale Observatory and the Watson Scientific Computing Laboratory to treat the planetary orbits by the method of mechanical quadrature

using an electronic computer. As we heard from Mr Clemence a few months ago, a step in calculation requiring from 20 to 40 hours by a skilled human computer is performed by mechanical means in approximately two minutes. So far, the work on the five outer planets has been completed for the years 1780 to 1940 and it is hoped to extend the calculations back to 1655 (the year of the earliest observations of the eclipses of the Jovian satellites) and forward to 2050. The completion of this programme, estimated to take up to a maximum of 25 years, will leave, it would seem, no further worlds to conquer in this long familiar field of celestial mechanics. It would be interesting to speculate on the reactions, if we could have them, of Newton, Lagrange, Laplace and the other great masters of gravitational theory, to these new developments; but space and time forbid an exercise of this kind.

The unique system of rings of Saturn has, curiously, inspired comparatively few mathematical astronomers to undertake investigations as to their origin, structure and stability; the mathematical problem is, of course, one of very great complexity and even now is not completely resolved. As far back as 1715 it was suggested by Cassini that the rings were composed of small satellites revolving around the planet in circular orbits; but, apparently, little attention was paid to this surmise. However, when the crepe ring was discovered and the ball of the planet seen through it, Cassini's interpretation received more solid support and was finally accepted when Clerk Maxwell published his classical investigation in 1856 which earned him the Adams Prize at Cambridge, founded in honour of J. C. Adams a few years before. The satellite-constitution of the rings received definite confirmation from Keeler's spectroscopic observations near the end of last century. One of the noteworthy features of the ring-system is the broad Cassini division, evidently a gap avoided by the ring-satellites; the vacuity of the division was confirmed by Ainslie's observations in 1917 when the ring-system passed in front of a seventh magnitude star which was seen undimmed in its passage across the division. It may be remarked that the phenomenon of Cassini's division (and Encke's) was not considered in Maxwell's theory.

The mathematical problem of the constitution of the rings with special reference to the divisions was taken up, just after the first world war, by G. R. Goldsbrough and later still by C. G. Pendse. One important result of a general nature is the recognition of the dissipative actions of Saturn's satellites in defining extensive zones of clearance within which the ring-satellites cannot long remain; one consequence is that the rings can no longer be regarded as a stable system but one subject to slow dispersal into the regions traversed by the planet's satellites. Particular results of the mathematical investigations may be briefly mentioned. The Cassini division represents one result of the perturbing action of Mimas, the satellite closest to the globe of the planet; Dione is mainly responsible for the clearance of ring-satellites up to a distance from Saturn in close agreement with the inner boundary of the crepe ring, the whole extent of which is within the dispersive field of action of Rhea and Titan; the latter satellite will, in course of time, cause the slow dispersal of the bright rings. Mimas is responsible for another effect, namely, the clearance of ring-satellites outwards from a certain distance which is almost exactly that given by the outer boundary of the ring-system. A complete mathematical theory, including the gravitational action of the ring-system itself, would no doubt be able to give

some indication as to when Saturn will be deprived completely of its incomparable rings; further—a much more difficult problem probably—it might lead to an estimate of the age of the ring-system, taking us back to what is believed to be the catastrophic event described in terms of the disruption of a Saturnian satellite which ventured, with fatal results to its individuality, within the danger-zone prescribed by Roche's limit. From the little I have said on this topic it will be evident, I think, that Saturn's rings still offer a challenge to the mathematical astronomer.

Perhaps the greatest need of astronomy fifty years ago was the rapid and accurate determination of a large number of stellar distances to form a reliable foundation for the deeper exploration of the galactic system and for investigating the physical properties of the stars. The heliometer in the hands, first, of Bessel and, later, of Gill and others had produced a limited number of successful parallax measurements for the nearest stars; but it was evident that the visual methods ceased to be effective for stars further away than a dozen, or perhaps a score, of parsecs. The introduction of photography into this exacting department of astronomy by Pritchard of Oxford in 1886 foreshadowed better things to come. As a result of immense efforts up to 1900 the parallaxes of about three score of stars had been determined, about half of which were within a distance of ten parsecs from the Sun; probably no more than a third of the total had been measured with a precision that would be regarded as tolerable on present-day standards.

It was almost exactly at the opening of the century that the first comprehensive programme of determining stellar parallaxes by photography was inaugurated by Hinks and Russell at Cambridge with the Sheepshanks telescope specially designed for the purpose. This was followed by Schlesinger's long series of measurements in America, so fruitful in technical advances amongst which perhaps the most notable was the introduction of the method of dependences. The measurement of parallaxes is still one of the staple investigations of some of our observatories, Yale Observatory and the Cape Observatory being the most prolific with over 1800 and over 1600 parallaxes to their respective credits.

One of the early results of the new knowledge of stellar distances was the recognition of the immense diversity of luminosity among the stars, from which followed the separation into two classes of giants and dwarfs. Then in 1914 came Adams' discovery of the spectroscopic method of deriving parallaxes—basically a method of deriving absolute magnitudes—which could be applied to any star, belonging to one of several spectral types, sufficiently bright to register a measurable spectrum irrespective of its distance from the Sun.

The measurement of the parallax of a binary star with a well-determined orbit led, by a simple application of Kepler's third law (in its precise form), to the calculation of the mass of the system and, in several cases, with the aid of observations of a different type, to the evaluation of the mass of each component. The binaries for which there was reliable information as regards both parallax and orbit appeared to show that the masses of these systems were close to twice the solar mass. The process could be reversed; by adopting twice the solar mass as the mass of the binary, the parallax could be deduced with an accuracy under the circumstances, which I need not elaborate, comparable with that attainable by direct measurement of the trigonometrical parallax. Eddington's

mass-luminosity relationship later introduced much greater precision into this latter method for, with a preliminary value of the parallax obtained as described, the corresponding absolute magnitudes of the two components are easily derived from the observed apparent magnitudes, the mass-luminosity relationship then giving the mass of each component; with the mass of the binary found in this way the parallax can be re-calculated and the procedure repeated *in toto* if necessary. This method of successive approximations applies only to systems for which orbits have been calculated.

In the case of slow-moving binaries for which only a small arc of the orbit has been observed, a statistical process can be applied which, in the skilful hands of H. N. Russell and Charlotte E. Moore, has yielded a large volume of information. Parallaxes determined in this way are known as dynamical parallaxes.

It is not easy to give a reliable estimate of the total number of parallaxes measured up to date. The Yale list (1935) contained entries for 7534 stars for which trigonometrical or spectroscopic parallaxes or both were known and, in addition, 1234 dynamical parallaxes. In the same year the Mount Wilson spectroscopic parallaxes totalled 4179 and Russell and Moore's list of dynamical parallaxes had 166 entries for binaries with reliable orbits and 2363 entries for slow-moving pairs. To summarize the work of the half-century we may say, allowing for poorly determined measures, that in round figures a grand total of 10,000 parallaxes of reasonable accuracy have been obtained by one or other of the methods described.

A deeper penetration into the galactic system is made possible by means of the absolute magnitudes of stars of different spectral types based, of course, on the ascertained parallaxes of the nearer stars. A complication is introduced by the interstellar cloud but I have no time to discuss this further. The observational and theoretical studies of Cepheid variables has enabled us to explore still further afield—to the globular clusters and the nearer extragalactic nebulae—and rougher methods take us to the farthest bounds of the visible universe.

It is probably true to say that the staple occupation of the majority of astronomers in the last century was the determination of stellar positions with the meridian circle. One obvious incentive was the attainment of increased accuracy in these fundamental observations so that the motions of the planets against the stellar background could be ascertained with the greatest possible precision. A second incentive was found in the determination of proper motions—the angular movements to which the stellar velocities relative to the Sun give rise. An observed proper motion consists of two parts, one resulting from the Sun's own motion with respect to the group of stars concerned and the other resulting from the star's individual velocity with respect to certain axes defined by the group. Until the beginning of our century the only important problem associated with proper motions in bulk was that of the solar motion—or rather its direction in the heavens, for it was only when radial velocities became available that the Sun's speed, relative to the group of stars concerned, could be found. The assumption underlying the determination of the direction of the solar motion was the simple one of the random character of the individual velocities as defined; the procedure consisted in averaging the proper motion components of the stars within a particular region of the sky in the expectation

that the random motions would cancel out, leaving a reliable value of each component which would then represent the true effect of the solar motion. The combination of such information from different parts of the sky—not necessarily the whole sky—then yielded the direction of the solar motion or, in other words, the coordinates of the solar apex. Although a large number of astronomers of repute analysed the observational data available to them for this purpose, it seems rather remarkable that no test of the fundamental hypothesis relating to the randomness of the stellar motions appears to have been undertaken until 1904, when Kapteyn discovered the phenomenon of the two star-streams, a discovery which may be said to have inaugurated the study of a much wider problem, namely, the dynamics of the galactic system itself.

If the individual motions of the stars in a small part of the sky were simply random in character, the distribution of the observed proper motions in position angle ought to be represented by a particular member of a family of oval curves, its axis pointing in a definite direction depending on the projection of the solar motion on the area of the sky concerned, and its relative dimensions depending on the angular distance of the region from the solar apex. Kapteyn's discovery consisted, first, in noticing that no such simple curve represented the observed distribution, so that the hypothesis of randomness in the original form must perforce be abandoned, and, second, that the observed distribution appeared to be the combination of two oval curves, one pointing to a particular apex and the other to a second apex, these apices being determined from the information supplied by several regions of the sky. Kapteyn's interpretation was in terms of two swarms, or streams, of stars each with its own motion in space.

The immediate developments were due to Eddington who, introducing Maxwell's law as a criterion of randomness for the stars of each stream, devised an effective method for the analysis of the stream motions which he applied in 1910 with great success to the 6000 proper motions of the naked-eye stars of Boss's *Preliminary General Catalogue*, just then published. I mention two of the principal results; first, when the solar motion was allowed for, the streams appeared to move in opposite directions (really a consequence of the definition of the solar motion) lying almost exactly in the galactic plane; second, the populations of the streams were in the ratio 3:2. The first result is expressed in terms of the vertex of star-streaming, towards or away from which the streams are moving; the longitude of the vertex was found to be 347°. Evidently the line joining the vertex to its antipodal point was of the utmost significance in relation to the general structure of the galaxy; but just what it signified in a spheroidal system with the Sun supposed, at that time, to be centrally situated was not elucidated for a decade and a half.

An alternative interpretation of the systematic motions of the stars was offered by Schwarzschild in the ellipsoidal hypothesis, according to which it was postulated that the stars had a greater mobility in the to-and-fro directions defined by the line of vertices than in any perpendicular direction. Analytically, the representations of the two conceptions are very much alike and so far they are practically indistinguishable in their applications to the observations, provided that the populations of the two streams are equal. As we have seen, the Boss stars gave the relative populations in the ratio 3 : 2; but when the proper motions of faint stars, derived photographically, are examined the disparity virtually disappears. At this point I may add that the proper motions

of the *General Catalogue*—about 33,000 in number and including all magnitudes to the ninth—show a significant diminution of the ratio to 6 : 5. It seems now to be reasonably well established that, in the much greater volume of space surveyed for the proper motions of stars to the twelfth or fainter magnitudes, the relative populations of the streams are identical. This is in general accordance with theoretical considerations, for in terms of galactic rotation one stream simply represents those stars whose orbital motions are directed towards the hemisphere of which one vertex is the pole, and the second stream towards the other hemisphere. From this point of view the separation of the stars into two streams may then be regarded as a convenient analytical device to represent the more general conception inherent in the ellipsoidal hypothesis which, in the much more comprehensive problem of galactic dynamics, we assume to be characteristic of the stars in all parts of the galactic system.

There are various arguments for believing that the Galaxy is not in a steady state and in this connection there is one observational result of great significance emerging from nearly every statistical study of systematic motions either according to the two-streams technique or to the ellipsoidal theory. For a system, symmetrical spatially and dynamically, we should expect the direction of the vertex as viewed from the Sun's excentric position to be identical with that of the galactic centre. Now, the distribution of the globular clusters and of faint stars remote from the galactic equator, the direct observations made recently by Stebbins to which I alluded here a year ago, and other considerations, all seem to be unanimous in placing the galactic centre at or near longitude 325°. The observational result referred to is that the longitude of the vertex is nearly 20° higher. Without any further discussion as to the dynamical implications, I venture to take this opportunity of drawing your attention to the most recent determination of the vertex just obtained from an analysis of the 33,000 proper motions of the *General Catalogue* by Dr T. R. Tannahill at the University Observatory, Glasgow; for all the stars considered, the longitude of the vertex turns out to be 343°, thus providing confirmation of the deviation referred to.*

It may be added that the equatorial coordinates of the solar apex are found to be (273°, +35°).

There is one matter of fundamental importance in connection with the subject I have just been discussing and that is the value of the constant of precession. The proper motion of a star recorded in a catalogue is derived from meridian observations separated by as long an interval as possible, and one necessary item of information is a reliable value of the precessional constant. The adopted value of this constant is that derived by Newcomb at the request of the conference of almanac superintendents in 1896. If, then, the value of the constant is accurate, the derived proper motion of a star will be ideally exact although in practice we must recognise that it will be subject to the accidental errors of observation. If, however, the precessional constant requires correction—I omit, for simplicity, consideration of the corrections for certain other factors that enter into the complete problem—then the deduced proper motion will contain a systematic effect. It now transpires, as we shall see in a moment, that the outstanding error in the precessional constant is anything but negligible and, in fact, for a goodly proportion of stars in a standard catalogue it produces inaccuracies in the proper motions which are a substantial fraction of the proper

* For further details, see p. 194.

motions themselves and are, moreover, of a systematic nature. Each component of proper motion contains, of course, the systematic effect arising from the solar motion, the balance between the observed and parallactic motion being ascribed partly to the star's random motion, the errors of observation and the precessional error mentioned.

Newcomb's investigation was based on a pair of equations for each star, connecting the observed components of proper motion in right ascension and declination with the three components of the solar motion (regarded as unknowns) together with the unknown error of the precessional constant. It is significant of Newcomb's thoroughness of outlook that he contemplated adding to his equations appropriate terms to take account of the possible revolution of the stellar system; this was, of course, long before galactic rotation was anything more than a mere speculation. Newcomb's separate solutions in right ascension and declination were not as accordant as had been hoped—one contributory factor was the neglect of the systematic rotational terms; however, a weighted mean of $0''{\cdot}82$ was taken to represent the correction to the centennial constant of precession. With the new value of the constant the values of the general precession and the luni-solar precession were tabulated at intervals of 25 years from 1725 to 2000—with these, it should be added, are associated secular terms of reliable accuracy. This tabular representation forms the basis for the computed places of the stars—and their proper motions—in the ephemerides.

The foregoing method of deriving the constant of precession, and the associated constants, is now being supplemented by new methods based on planetary orbits. The principal requisite is an accurate theory of the planet concerned, either on traditional lines or by mechanical integration, and this involves an exact knowledge of the individual masses of the planets for evaluating the perturbations produced on the planetary orbit selected. Investigations along these lines have already been undertaken, notably in the U.S.A., giving an additional correction of about $+0''{\cdot}8$ to Newcomb's value of the centennial precessional constant; the accuracy of this result is, however, not particularly high.

As has already been remarked, Newcomb's basic equations are incomplete, for they do not take account of the systematic effects of the galactic rotation on the components of proper motion. A quarter of a century ago, Oort attacked the problem of the precessional constant in a novel way, the data used being the observed proper motions of stars lying in or near the galactic equator. The effects of the solar motion (assumed known) were first removed and the resultant components of proper motion in galactic latitude deduced. Such a component will of course contain the effect arising from the error of the precessional constant and, in addition, that arising from the star's component of velocity perpendicular to the galactic plane. According to the simple rotational theory, these velocity components are accounted random in character so that their effects on the components of proper motion in galactic latitude can be regarded, statistically, as of the same class as accidental errors. An equation then can be derived connecting the precessional error with these components. Oort's original solution showed that the correction to the precessional constant amounted, centennially, to $+1''{\cdot}13$, with a probable error of about one-ninth of this value. The more likely value favoured today is somewhat smaller and not greatly different from that derived from the planetary investigations mentioned earlier.

It is hardly necessary to stress the importance of an accurate determination of the precessional and allied constants in all investigations involving proper motions and particularly in the problem of galactic rotation. The current theory of galactic rotation may be succinctly defined in terms of the two constants A and B introduced by Oort; the former is derived directly from the radial velocities of the distant O and B type stars; the components of proper motion in galactic longitude involve both constants. Apart from the need of increased accuracy in meridian observations over a sufficiently long interval, the principal desideratum is an accurate evaluation of the precessional constant. It might seem that, if we depend only on proper motions as in Newcomb's investigation, we shall have to wait for some considerable time before this essential information is at our command, ready to be applied in elucidating more accurately than is possible at the present time the dynamical characteristics of the stellar system.

In 1947 there appeared the first papers—in *Monthly Notices*, **107**—on a new branch of our science, radio astronomy, which was also the subject of a special article by Dr Hey in the Report of Council at our anniversary meeting two years ago. Although the initial discoveries were made just before the second world war the rapidity of recent progress can be ascribed, in the first instance at least, to the well-known developments in radar technique during the period of hostilities. It must be a peculiar satisfaction to the Society that in the van of discovery in what to some of us is an occult art there are many of our own Fellows. The earlier investigations were concerned mainly with meteors; now the focus of interest seems to have moved to the depths of interstellar and extragalactic space, where new mysteries have been detected offering to our best minds a challenge for their elucidation and interpretation in the years to come.

It has long been known that the principal meteor showers are connected with periodic comets, the inference being that these humble particles of cosmic matter represent the cometary debris dispersed through planetary perturbations. As regards the sporadic meteors the chief problem is that relating to their origin. Are they to be regarded as belonging to the solar system or do they come from interstellar regions? The criterion is one of velocity; in a head-on collision an observed velocity exceeding 72 kilometres per second would undoubtedly point to an interstellar origin; for other kinds of impact there are corresponding critical velocities. Until fairly recently there seemed to be an acute divergence of opinion as to meteoric origins. On one hand Öpik's observations during the Arizona expedition in 1931–33 and the Tartu observations of 1934–38 appeared to show that at least 60 per cent of several hundreds of sporadic meteors had hyperbolic velocities. On the other hand, Whipple's photographic observations and Porter's exhaustive analysis of British meteor data failed to reveal any meteors of interstellar origin; as the new radio observations are entirely confirmatory of the second results, the balance of evidence is now strongly in support of the contention that meteors, of all kinds, are intrinsically members of the solar family.

The radio method of meteor observations is based on the fact that the trail of electrons, produced by a cosmic particle rushing at high speed through the upper reaches of the atmosphere, is capable of reflecting an incident radio-wave giving rise to a short-lived response which can be detected by a suitable receiver. The measurement of meteor velocities was first achieved with radio apparatus by Hey, Parsons and Stewart in 1947; since then a new technique has been

developed based on the diffraction of radio-waves from the meteor's electronic trail, analogous to the familiar phenomenon of the diffraction of light at a straight edge. It is calculated that for a bright meteor the number of electrons torn from the atmospheric molecules is of the order of a billion per centimetre of the meteor's visible path. Reliable estimates of the sizes of these small bodies appear to show that their diameters are of the order of one-hundredth of a centimetre—not far removed from the size of a grain of sand, the traditional, if speculative, answer to the question : " How big is a meteor ? "

Radio astronomy is independent of climatic conditions and can be pursued as well in daylight as in the long watches of the night. It is perhaps some recompense for the notoriously inclement weather of Manchester, as commonly alleged, that some of the most important developments in radio astronomy are now taking place at Jodrell Bank nearby, under the direction of Dr Lovell of the University Physics Department. Just after the end of the war, daylight observations revealed intense meteor activity, and up to date Lovell and his associates have clearly recognized about a dozen different streams, one of which appears to be associated with Encke's comet. A remarkable fact connected with the daylight streams so far fully investigated is that their orbits all lie within the orbit of Jupiter and are unrelated to any known short-period comet with, of course, the exception of Encke's. The suggestion has been made by Lovell that these streams appear to be related to the orbits of the minor planets, in which event the meteors are but the fine debris of whatever cataclysm produced the minor planets. On the other hand, if meteors are generically part of the debris of comets, the daylight streams may then be the remaining evidence of comets long defunct.

The first suggestion can be discussed in greater detail. When Olbers discovered the second minor planet he suggested that the two small bodies Ceres and Pallas were fragments of a larger planet disrupted in some kind of celestial explosion, a speculative and, to us nowadays, an entirely improbable event. That the asteroids, of which Baade estimates that about 40,000 are within the compass of the great telescopes, have a common origin is still an article of astronomical faith. The idea of an explosion of a large planet can be summarily dismissed, and the fracture of such a planet through too rapid rotation is improbable. As Jeffreys has shown, tidal action as a disruptive agent can also be ruled out. According to Kuiper the only phenomenon that can account for the asteroidal family is a collision of two small planets in the distant past and the successive mutual collisions of the fragments. In support, many of the asteroids are known to be of irregular shape—Eros, as we have seen, is a notable example. A recent estimate by Schuette of Munich puts the total mass of the asteroids at rather more than one quarter that of the Moon; even if we assume that Ceres, Pallas and one or two others have escaped collisions, there is evidently plenty of material left to have originally constituted two or three small planets each with a diameter of the order of perhaps 800 miles. The daylight streams apparently fit into this collision-hypothesis.

We now come to one of the most remarkable discoveries of recent years. It has been known for some time that the Sun emits radio waves, by what mechanism appears to be unresolved at present, and that there is a general contribution of the same nature from the Galaxy itself with the greatest intensities from the Milky Way regions, the maximum being in the direction of the galactic

centre. One important conclusion seems to be that, even if every star in the Galaxy is an exact replica of the Sun in this respect, the sum-total of the effects is only a negligible fraction of the general galactic emission. In 1945 Hey detected strong radio-emission from a restricted region in Cygnus; more recently, Bolton and Stanley in Australia and Ryle and Smith at Cambridge have found that with increased resolving power the radio waves appeared to come from comparatively minute areas of the sky generally remote from bright stars or from such objects as the dark or luminous nebulae. One notable exception places the seat of emission in the direction of the Crab Nebula, but whether this is actually located in the nebula itself or somewhere in the foreground is still to be settled.

An inference from these striking discoveries is that the emissions emanate from discrete bodies to which the appropriate name of "radio stars" has been given and of which about a hundred have so far been detected. A further deduction appears to follow, namely, that the general galactic emission already noted is an integrated effect from these individual sources.

A few months ago the radio astronomers at Jodrell Bank carried out a series of very remarkable observations— for information on this and other allied matters I am greatly indebted to Dr Lovell. The tower of the great 220-foot paraboloid is vertical and so only zenithal observations are normally possible. Hanbury Brown suggested that if the structure could be tilted 14° from the vertical in the meridian the Great Nebula in Andromeda would come within the sphere of observation. This difficult operation was safely accomplished and with new receiving apparatus of greatly increased sensitivity, radio emissions from the nebula were successfully observed. Our Galaxy is then not unique as regards these new radio phenomena and I do not think that I would be accused of rashness if I suggest that the extragalactic nebulae in general have within them sources, similar to those in our Galaxy, radiating low-frequency electromagnetic waves far beyond the red end of the familiar optical spectrum.

The principal problem to be solved is, of course, concerned with the physical processes operating in the discrete bodies envisaged and producing the type of radiation observed. To the orthodox astronomer one problem relates to the number and distribution of the radio stars. The discovery of such a large number of these objects with apparatus evidently just on the threshold of sensitivity would seem to lead to the conclusion that radio stars are very numerous in our Galaxy. Are they as numerous as the lucid stars and have they a similar galactic concentration? The answers to these questions will be awaited with the greatest interest.

If radio stars are essentially nuclei of matter with masses of the same order of magnitude as those of ordinary stars, their gravitational effects must be included in those that are observable as galactic rotation. Until the advent of these new bodies the best available information indicated, for a first approximation at least, that the galactic system consisted of a nucleus of $10^{11}$ stars of average solar mass together with a spheroidal distribution of nearly equal aggregate mass, the latter including the interstellar clouds. The determination of the relative distribution of lucid stars, radio stars and interstellar matter provides a new problem to investigators of the material and dynamical characteristics of the Galaxy, a problem in which the skill and the patience of the practical astronomer will be called upon perhaps as never before.

Fifty years ago the exploration of the Universe beyond the confines of the solar system had scarcely begun and had certainly made but modest progress. A quarter of a century ago we were still discussing in formal debate whether or not the spiral nebulae should be regarded as constituent members of the galactic system. Today we have before us a vast accession of knowledge in many departments of our science but nevertheless we are still confronted with problems of ever-increasing complexity. If my successor in the presidential chair in 2001 adopts as the subject of his anniversary address "A review of the past half-century"—an occasion at which many of us would give a lot to be present—he will no doubt refer to the little that was really known in 1951 as compared with the immense advances made in his life-time. But will he not have to confess that new and urgent problems, of which we do not have now the smallest inkling, are still rising above the scientific horizon demanding elucidation and interpretation? The history of science would appear to answer: "Yes".

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*Printed in London by Taylor & Francis, Ltd., 1951 October.*